ORBIT

SECOND/THIRD QUARTERS 1999 VOL.20 NO.2

INSIDE THIS ISSUE:

New Product: An actively controlled fluid bearing

Magnetic bearings … do their problems outweigh their benefits?

Case History: Using Data Manager® 2000 to compete in the wholesale power market

Why phase information is important for diagnosing machinery problems

Update: Snapshot™ for Windows® CE – Bently Nevada's next-generation portable data collector

Getting to know Bently Nevada's management team – Part 4

all (ôl) adj. 1. The total en[illegible]ty [illegible]r extent of 2. Being the whole [illegible]mb[illegible]r, [illegible]ua[illegible]tity, or amount of 3. Bei[illegible] [illegible]most possible 4. Every 5. Any [illegible]atsoever 6. Nothing but: [illegible]ach: apiece 3. Exclusively

…all your machinery

temperatures

portable systems

training

flows

position

vibration

on-line scanning systems

expansion

overspeed

casing transducers

fluid-film bearings

project management

machinery protection

services

active bearings

general-purpose machinery

off-line systems

machinery management

critical machinery

system integration

portable data collection

on-line systems

continuous systems

proximity probes

rolling element bearings

permanent systems

essential machinery

HELPING YOU PROTECT AND MANAGE $\overset{all}{\wedge}$ YOUR MACHINERY®

BENTLY
Nevada

EDITOR'S NOTE

... Your Machinery

all

... *all* your machinery. It's a most fitting theme for this issue of the ORBIT magazine. While our business today is all about machinery, in truth, Bently Nevada did not start as a company focused on rotating and reciprocating machinery. Don Bently's original "office" was a garage in Berkeley, California, where he sold transducers via mail-order to a wide variety of customers. It would be a number of years before the transducer found its way into a rotating machine and a whole new instrumentation industry would be born. Today, over forty years later, you've helped us become the world's leading provider of machinery protection and management systems.

As we've grown, however, we've become strongly identified as the company that makes eddy current proximity transducers and continuous vibration monitoring systems to protect turbomachinery. Yes, that's a big part of what we do – but it isn't all we do! We know that, while turbomachinery may be the most critical machinery in your plant, there are often thousands of other machines that must be managed as well. Some dictate continuous measurements, others portable data collection, and still others an intermediate approach that provides the benefits of continuous data acquisition without the attendant costs of a "traditional" machinery protection system. Because you have different kinds of machinery, we understand that we need to provide cost-effective solutions that address "all your machinery."

In this issue, we're pleased to showcase the first of a series of new products designed to address all your machinery needs and integrate into an easy-to-use *system*. Beginning later this year, you'll be able to use an improved Bently Nevada portable data collector to address your off-line predictive maintenance needs. We invite you to read about this exciting product on page 32. Now, glance back at the first sentence of this paragraph. You'll note that we emphasized the word "*system*." That word was chosen very deliberately. Until now, your alternatives for machinery management consisted of stand-alone products without a common software environment to link them all together. It wasn't a system; it was a collection of components. On page 33, we're going to introduce you to System 1™ – our exciting new software platform that will give you just that: one system for managing all your machinery.

You'll find this issue contains a wealth of articles addressing many different kinds of machines – from the new valve position monitor for large steam turbines in power generation service (page 37), to the active research Bently Nevada is doing on general-purpose pumps and motors (page 46), to the revolutionary new Bently ServoFluid™ control bearing (page 15) – a product destined to change the way machines are designed and operated in the future.

Finally, we continue to introduce you to some of the people of Bently Nevada. Starting on page 8, you'll find an informative interview with some of Bently Nevada's executives and their thoughts about how the Company will meet the challenges of today and tomorrow.

Credits Actionable Information™, Actionable Information to the Right People at the Right Time™, ADRE®, Bently Align™, Bently Balance™, Bently Nevada®, CableLoc™, ClickLoc™, Data Manager®, Decision Support™, DemoNet™, Dynamic Data Manager®, Dynamic Transmitor™, Engineer Assist™, FieldMonitor™, FluidLoc™, flexiTIM™, flexiTAM™, Helping You Protect and Manage *all* Your Machinery®, HydroVU™, Keyϕ®, Keyphasor®, Machine Condition Manager™ 2000, MachineLibrary™, Machine Manager™, MicroPROX®, Move Data, Not People®, Move Information, Not Data™, NSV™, Preformalign™, Process Centered Maintenance™, PROXPAC®, Proximitor®, REBAM®, Seismoprobe®, ServoFluid™, Smart Monitor®, Snapshot™, System 1™, System Extenders™, TDXnet™, TDIXconnX™, Tecknowledgy™, TipLoc™, TorXimitor®, Transient Data Manager®, Trendmaster®, TrimLoc™, VAM™, Velomitor®, XLerometer™.

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allowing you to expand the capabilities of your portable program. Snapshot will grow in functionality, protecting your investment over time.

Must integrate the "on-line" and "off-line" worlds...

Snapshot is "System 1™ enabled." That means it, and other Bently Nevada data acquisition hardware, will communicate with our soon-to-be-released System 1 machinery management software. *This major step forward will evolve to allow you to integrate off-line data (from Snapshot for Windows CE) and on-line data (from numerous Bently Nevada and third-party products) in a single database and display environment.* This integrated platform will allow users to reap the benefits of combining Bently Nevada's *proven*, continuous, on-line data acquisition system (including automated transient data collection) with off-line data. *You view all classes of machinery assets in a single display environment.*

The System 1 machinery management software will act as the Snapshot application software. System 1 can be used cost-effectively as a stand-alone system with Snapshot for Windows CE to provide off-line data storage, display, and diagnostics. It will also provide future support for Bently Nevada's continuous, on-line data acquisition systems for integrated off-line and on-line data.

Want to know more?

For information on System 1 and Snapshot™ for Windows® CE, visit www.bently.com/mktreference.htm, or contact your nearest Bently Nevada sales professional.

ANNOUNCEMENTS

Don Bently gives Keynote Address at Nevada Economic Development Commission

While Nevada is best known as a "24-hour" state with an economy centered on tourism and gambling, its future economic base will need to diversify to include more high-tech industries. Such was the topic of the recent conference of the Nevada Economic Development Commission, which brought together nearly 100 of the state's experts in science, industry, and technology from private industry, government, and education. The keynote speaker? None other than Bently Nevada's owner, founder, and Chief Executive Officer, Donald E. Bently.

Mr. Bently discussed how he was able to increase Bently Nevada's size from just 3 people when he relocated Bently Scientific Company from California to Nevada in 1961. It has become the high-tech leader in its field, employing over 1600 people worldwide, 950 of whom are located at its corporate headquarters in Minden, Nevada. Bently Nevada is enjoying its 44th year of continuous, profitable operation.

If you are interested in reading Don Bently's speech, please go to our website – **www.bently.com/mktreference.htm**.

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Quality Assurance Manager

Raymond J Case
Sr. Vice Pres. Finance and Administration

Leif Lauridsen
ERP Project Leader

Steve Sabin
Corporate Marketing Manager

Jeff Davey
I.S. Manager

Christopher P. Bently
Vice-Chairman

Richard A. Chapman
Exec. V.P. / General Manager

Agnes Benis
Internal Auditor

Donald E. Bently
Owner / Chairman / C.E.O.

Reidar Wahl
V.P. Manufacturing

Randy Chitwood
V.P. Engineering

Roger G. Harker
President / C.O.O.

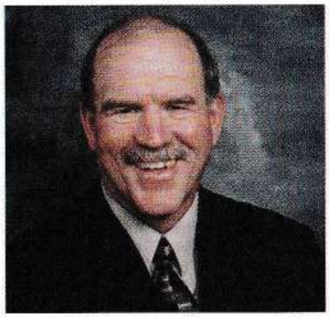
Steven W. Riggs
Sr. V.P. Sales and Service

Moving into the future

Getting to know the Bently Nevada management team – Part 4

Richard A. Chapman
is Executive Vice-President / General Manager. Rich has been with Bently Nevada for 26 years in various positions within sales, service, and engineering. He presently oversees the day-to-day operations of the Company, with all department vice-presidents/senior managers reporting to him.

Steven W. Riggs
is Senior Vice-President, Sales and Services. Steve has been with Bently Nevada for 30 years and is responsible for all global sales and service activities through a network of 82 technical support locations in over 40 countries.



Randall R. Chitwood
is Vice-President, Engineering. Randy has been with Bently Nevada for 20 years and is responsible for all hardware and software product development worldwide, as well as product research initiatives.

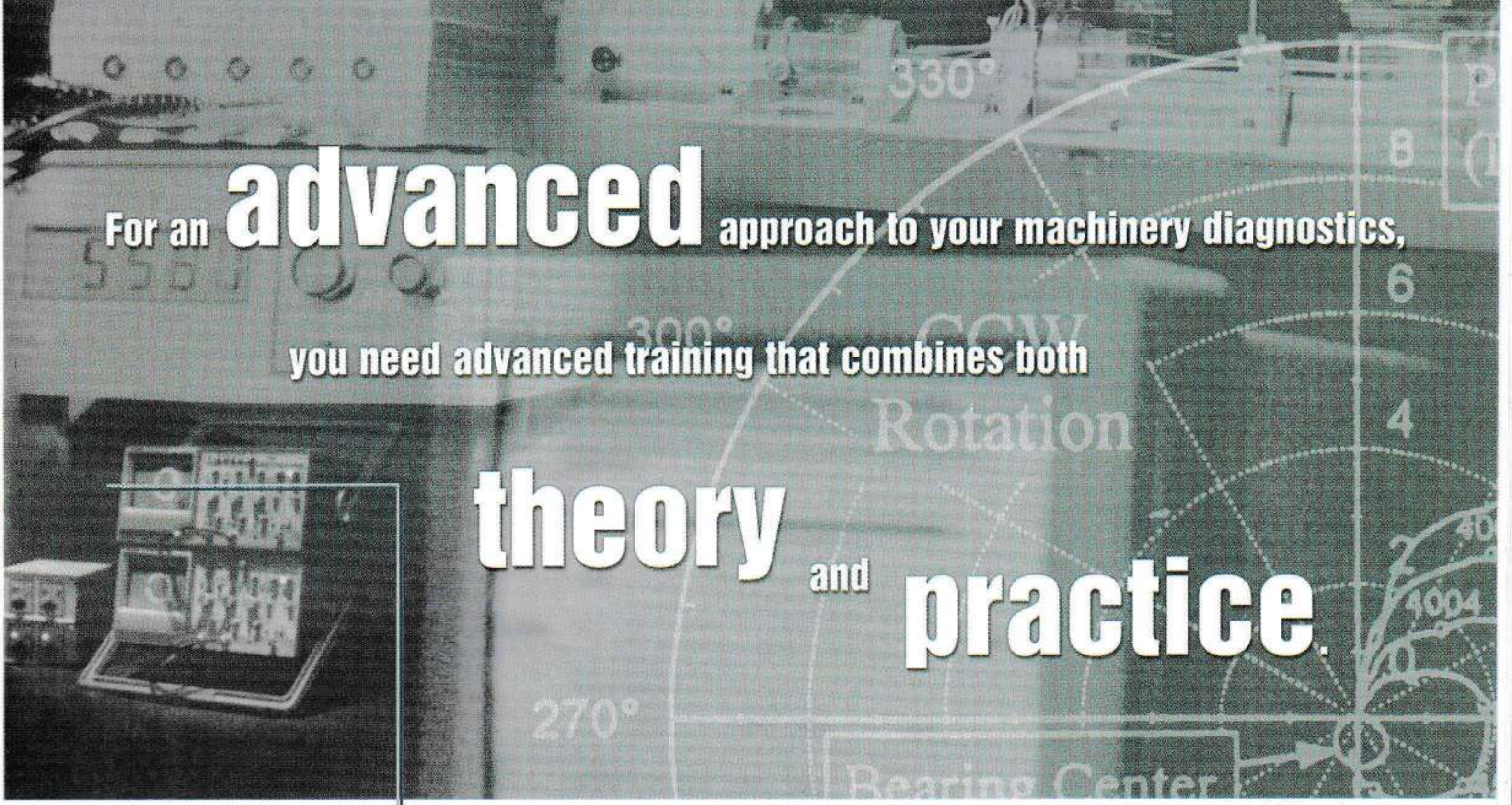
Steven J. Sabin
is Corporate Marketing Manager. Steve has been with Bently Nevada for 10 years and is responsible for macro market understanding functions and global product/company promotional functions.

In 1998, ORBIT magazine interviewed Bently Nevada's owners, Donald and Christopher Bently, as well as Bently Nevada's president, Roger Harker. These interviews provided insight into the long-range goals and vision for the Company. In this issue, we'd like to continue by allowing some of the people who are responsible for implementing that vision and mission to talk about their activities and how they'll move the Company forward consistent with our vision. ORBIT magazine recently spent some time with Executive Vice-President Richard Chapman and several of his key department heads in Engineering, Sales and Service, and Marketing. Here's what they had to say...

The Bently Nevada mission statement – "Helping you Protect and Manage *all* your Machinery" – how important is it to the Company?

Chapman: It's what we do to add value for our customers and to keep us focused on what we do for a living. What could be more important than that?

Riggs: So many mission statements these days are a collection of platitudes that provide little real direction to employees, and no real communication to customers and other "stakeholders." The fact that virtually anyone in the Bently Nevada organization can sit down with a customer and explain the meaning and relevance of



For an advanced approach to your machinery diagnostics, you need advanced training that combines both theory and practice.

That's why our Advanced Machinery Dynamics Course is unique. You'll not only learn theory covering advanced rotor dynamic concepts directly from one of the world's foremost authorities – Donald E. Bently – you'll also apply what you learn in hands-on workshops using rotor kits and standard diagnostic tools. The Advanced Machinery Dynamics Course is presented by Bently Rotor Dynamics Research Corporation (BRDRC) and features case histories, demonstrations, hands-on laboratory exercises, and rich discussion opportunities with your peers and our instructors and scientists. It builds on the fundamentals established in our Machinery Diagnostics Course by equipping you to:

- advance your machinery vibration diagnostic skills
- evaluate rotating machinery design and operating parameters
- identify corrective actions
- prevent machinery malfunctions
- create an effective, condition-based machinery management program

If you are a machinery designer, machinery engineer, maintenance engineer, postgraduate student, researcher, or professor involved in rotor dynamics, we invite you to join us for this unparalleled learning opportunity.

Donald E. Bently is founder and CEO of Bently Nevada Corporation, and President of BRDRC. Mr. Bently is actively involved in machinery dynamics research & product development. He received a Master's degree in Electrical Engineering – University of Iowa and an Honorary Ph.D. – University of Nevada, Reno.

Abu Dhabi, United Arab Emirates, 6-10 November 1999

Registration fee: Early – 1,975 USD (prepaid 4 weeks in advance) Regular – 2,225 USD

Tuition includes continental breakfast and lunch each day, and one dinner. Lodging not included. Credit cards are accepted.

To register, contact Bently Nevada Technical Training or your nearest Bently Nevada office.

BENTLY ROTOR DYNAMICS RESEARCH CORPORATION

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Phone: 775.782.3611 · 800.227.5514
Fax: 775.782.9305
Website: www.bently.com

BENTLY Nevada

...all

your machinery

(That means off-line portable data collection too!)

snapSHOT™
for Windows® CE

- Surveillance and diagnostic modes – a *single* tool for operators and specialists
- Battery life – 8 hours *minimum*
- Lightweight (approximately 4 lbs!), single-handed operation
- Crystal-clear, backlit LCD display
- Touch-screen user interface – simple to use
- Two full-function channels *plus* Keyphasor® input
- Rugged IP65 sealed case
- Industry-standard Windows® CE operating system
- PCMCIA slot for memory, programming, and hardware connectivity
- Ethernet and serial communications

SYSTEM 1™
Enabled

What if you could take Bently Nevada's on-line machinery protection and management systems and combine them with portable data collection? What if you could finally manage all your machinery – regardless of how you chose to collect the data – from a single, unified software environment?

You can.

Announcing Snapshot™ for Windows® CE, Bently Nevada's portable data collector. Snapshot™ for Windows® CE is destined to be your next portable data collector – a data collector that will evolve to be totally integrated with your on-line system via our System 1™ software. A data collector with the power and features you need to address the hundreds or even thousands of machines in your plant that don't lend themselves to an on-line system. A data collector that does everything you need – and more – yet at a price that's considerably less than what you're probably paying for someone else's non-integrated solution.

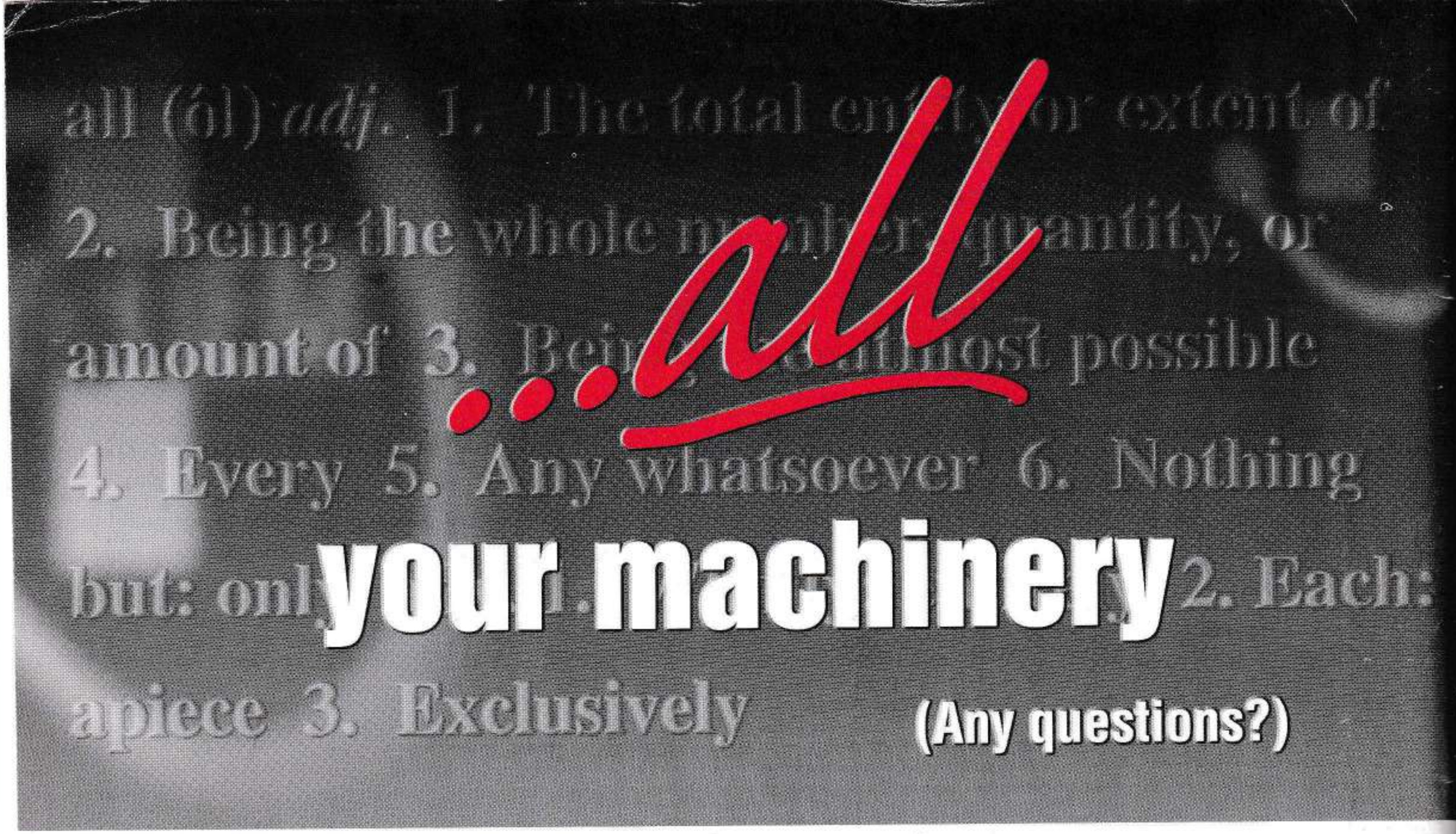
Interested? We thought so. That's why we've prepared an information packet that explains not just Snapshot™ for Windows® CE, but the entire System 1™ software platform that's designed to integrate the Bently Nevada products you may already be using with the portable data collector that's going to change everything. To get your information packet, visit us on the world wide web at www.bently.com/mktreference.htm or contact your nearest Bently Nevada sales professional and request the Snapshot™ for Windows® CE information packet. Snapshot™ for Windows® CE and System 1™ – machinery management will never be the same again. Coming fourth quarter 1999.

1(800) 227-5514 (USA only)
1(775) 782-3611
[44] (1925) 818504 (UK)

This product is not currently for sale, and this ad is not an offer for sale.

BENTLY®
Nevada

HELPING YOU PROTECT AND MANAGE *all* YOUR MACHINERY®


all (ôl) adj. 1. The total entity or extent of
2. Being the whole number, quantity, or
amount of 3. Being the utmost possible
4. Every 5. Any whatsoever 6. Nothing
but: only
...all
your machinery
2. Each:
apiece 3. Exclusively
(Any questions?)

SYSTEM 1®

What if a tool existed that could reduce your costs of training and maintenance for numerous stand-alone software applications and instead let you manage every machinery asset in your enterprise from a single, powerful program? What if this tool let you build a more extensive system without fear that upgrades and revisions will render your database and integration to other plant systems obsolete? What if this tool let you expand in a modular fashion – adding portable data collection today, on-line continuous data acquisition tomorrow, and on-line scanning data acquisition in the future? What if this tool let you add extended functionality with separate components, such as balancing, oil analysis, performance, alignment, document management, Decision Support™, and others?

It does.

It's called System 1™ and it will change the way you manage your machinery. That's because you'll be able to concentrate on your machines – all of them – from a single, integrated application that's easy to learn, easy to use, and more powerful than anything before it.

Interested? We thought so. That's why we've prepared an information packet that explains the entire System 1™ software platform. To get your information packet, visit us on the world wide web at www.bently.com/mktreference.htm or contact your nearest Bently Nevada sales professional and request the System 1™ information packet. Coming fourth quarter 1999.

1(800) 227-5514 (USA only)
1(775) 782-3611

System 1™ will evolve to include:

- Off-line and on-line data aquisition
- Rolling element bearing support
- Data import and export capabilities using open protocols
- Decision Support™ connectivity
- Performance Monitoring
- Oil analysis
- ...and more!

HELPING YOU PROTECT AND MANAGE ^all YOUR MACHINERY®

BENTLY
Nevada

1999 Global Training Schedule
October - December

(Arranged chronologically by country)

Date	Course Description	Country	Location
October 11-13	3300 Installation & Maintenance	Australia	Sydney*
October 18-20	3500 Installation & Maintenance		Sydney*
October 25-27	Alignment Fundamentals		Sydney
November 8-10	Getting the Most from Data Manager® 2000		Sydney
November 16-19	Machinery Diagnostics		Sydney
November 22-25	Applied Diagnostics Workshop		Sydney
October 5-8	3300 Installation & Maintenance	Canada	Montreal, Quebec*
November 2-5	3300 Installation & Maintenance		Canmore, Alberta*
November 23-25	Getting the Most from Trendmaster® 2000		Edmonton, Alberta
November 30-December 3	3500 Installation & Maintenance		Edmonton, Alberta
December 7-10	Getting the Most from Data Manager® 2000		Edmonton, Alberta
October 19-21	Data Acquisition & Machinery Monitoring	France	Nantes
November 22-26	Machinery Diagnostics		Nantes
December 6-10	Machinery Diagnostics		Nantes
October 12-14	3300 Installation & Maintenance	Germany	Neu-Isenburg/Frankfurt*
October 20-22	Getting the Most from ADRE® for Windows		Neu-Isenburg/Frankfurt
October 27-29	3500 Installation & Maintenance		Neu-Isenburg/Frankfurt*
November 3-5	Getting the Most from Data Manager® 2000		Neu-Isenburg/Frankfurt
November 30-December 3	Machinery Diagnostics		Neu-Isenburg/Frankfurt
December 6-9	Applied Diagnostics Workshop		Neu-Isenburg/Frankfurt
October 26-28	3300 Installation & Maintenance	India	New Delhi
December 14-16	3300 Installation & Maintenance		New Delhi
December 21-23	Machinery Diagnostics		Baroda
October 13-15	3300 Installation & Maintenance	Korea	Seoul
October 20-22	Getting the Most from Data Manager® 2000		Seoul
October 27-29	Getting the Most from Trendmaster® 2000		Seoul
November 15-19	Machinery Diagnostics		Seoul
December 6-10	Data Acquisition		Seoul
December 13-17	Machinery Diagnostics		Seoul
October 6-8	Data Acquisition	Malaysia	Kuala Lumpur
November 8-12	Machinery Diagnostics		Kuala Lumpur
November 15-18	Applied Diagnostics		Kuala Lumpur
October 5-7	Data Acquisition & Machinery Monitoring	The Netherlands	Pijnacker
October 11-15	Machinery Diagnostics		Pijnacker
October 26-28	Getting the Most from Trendmaster® 2000		Pijnacker
November 8-12	Applied Diagnostics Workshop		Pijnacker
November 16-18	Getting the Most from Data Manager® 2000		Pijnacker
December 7-9	3300 Installation & Maintenance		Pijnacker*
December 14-16	3500 Installation & Maintenance		Pijnacker*
October 20-22	Getting the Most from Trendmaster® 2000	Philippines	Manila
November 17-19	Getting the Most from Data Manager® 2000		Manila
December 12-17	Applied Diagnostics		Manila
November 20-24	Data Acquisition & Machinery Monitoring	Saudi Arabia	Dammam
November 27-December 5	Machinery Diagnostics		Dammam
December 6-8	Getting the Most from Data Manager® 2000		Dammam
November 6-10	Advanced Machinery Dynamics	United Arab Emigrates	Abu Dhabi
October 5-7	3500 Installation & Maintenance	United Kingdom	Warrington*
October 18-22	Machinery Diagnostics		Warrington
November 2-4	Getting the Most from Data Manager® 2000		Warrington
October 6-8	3500 Installation & Maintenance	United States	Media, Pennsylvania*
October 11-13	Getting the Most from Data Manager® 2000		Media, Pennsylvania*
October 13-15	Getting the Most from ADRE® for Windows		Houston, Texas
October 18-22	Machinery Diagnostics		Houston, Texas
October 19-21	3300 Installation & Maintenance		Media, Pennsylvania*
October 26-28	Alignment Fundamentals		Houston, Texas
October 26-28	Getting the Most from Trendmaster®2000		Media, Pennsylvania
November 2-4	3300 Installation & Maintenance		Houston, Texas*
November 3-5	Getting the Most from ADRE® for Windows		Media, Pennsylvania
November 8-12	Machinery Diagnostics		Media, Pennsylvania
November 9-11	Getting the Most from Data Manager® 2000		Houston, Texas
November 15-19	Applied Diagnostics Workshop		Media, Pennsylvania
November 16-18	3500 Installation & Maintenance		Houston, Texas
November 29-December 3	Machinery Diagnostics		Houston, Texas
November 30-December 2	Alignment Fundamentals		Media, Pennsylvania
December 6-10	Applied Diagnostics Workshop		Houston, Texas
October 18-22	Machinery Diagnostics	Venezuela	Maracaibo
November 8-10	Getting the Most from Data Manager® 2000		Maracaibo

Please call your nearest Bently Nevada office for the latest information or contact our Technical Training Department. In the United States, call toll-free 800.227.5514 ext. 9682. Outside the United States, call 775.782.3611 or fax 775.782.9305. Our seminar information is also available on the Internet - www.bently.com.
Seminars are usually conducted in the language customarily spoken in the host country. *Optional one extra day for additional topics.

provides two fully-enabled, identical data acquisition channels plus a separate Keyphasor® phase reference input. If you're used to using two different products – one for surveillance and another for diagnostics – prepare to simplify your life with a single, powerful product that delivers the best performance on the market.

Must be lightweight and ergonomically-designed...

Snapshot is lightweight (approximately 4 pounds!), so it can be held easily in one hand. The hand strap and keypad design, along with its light weight, mean that you can hold and operate the Snapshot with either hand.

Must be rugged...

To operate every day in a harsh plant environment, Snapshot has been designed to meet the stringent requirements of IP65. The product has undergone a thorough development program, using computer modeling techniques and impact and drop tests during all phases of development. This means it won't let you down when you need it most. Because you're working on and around machinery, we've made the product with breakaway transducer cables to ensure you're using a product that's safe and rugged.

Must be easy to see...

A clear, easy-to-read, backlit display ensures you can not only collect data, you can *see* it. Snapshot's in-field alarms mean you can see at a glance if the machine is experiencing abnormal conditions while you're collecting data – no need to wait until you connect to the host computer and transfer data.

Must permit a full day's work...

Snapshot's battery lasts a minimum of eight hours when you're in the field collecting or diagnosing data. With its internal transducer power supply, there's no need to carry additional boxes for powering transducers.

Must be flexible...

Multiple data collection schedules can be loaded into Snapshot. The selected schedule is easy to navigate and can be quickly modified in the field. Unsure about anything? You can simply use Snapshot's built-in help system for easy, intuitive guidance on how to get the most from your instrument. Additionally, Snapshot uses the Microsoft Windows CE operating system, which gives a familiar look and feel to its operation. The result is a user-friendly instrument with minimal training needed for the user interface. For additional flexibility, you can use your Snapshot with either the keypad or the integral touch screen, even when you're wearing gloves.

Must be a platform for the future...

Snapshot™ for Windows® CE has been designed for the future – the basic hardware provides a platform for future expansion. We will be adding software utilities (such as balancing) and hardware connectivity (such as alignment and automatic point identification),

About System 1

System 1™ is a true machinery management platform. Its phased development ensures your initial System 1 investment will increase in functionality over time – protecting your machinery management system investment as it matures by allowing you to migrate from what you are using today to an integrated platform of tomorrow. This phased development will result in a machinery management platform that will eventually incorporate:

- Off-line, periodic on-line, and continuous on-line data acquisition.
- Rolling element bearing support.
- Data import and export capabilities with industry-standard data transfer methods, such as OPC (OLE for Process Control) and others.
- Support of selected existing – and all new – machinery protection monitoring and data acquisition systems from Bently Nevada.
- Integrated Decision Support™ capabilities for all classes of machinery.
- Integrated performance monitoring.
- A rolling element bearing database with information from numerous manufacturers, including part numbers, dimensions, number of elements, etc.
- Oil analysis and other predictive maintenance technologies.
- *And much more…*

Upon initial release, System 1 will provide support for our new Snapshot™ for Windows® CE data collector. From this, System 1 will grow to include support for selected Bently Nevada Communications Processors, our Trendmaster® 2000 hardware, and other data acquisition devices. This phased product development plan to expand System 1 capabilities, as outlined here, keeps Bently Nevada at the forefront of machinery management solutions for *all* your machinery.

using our more recent transducer suites, protection systems, data acquisition devices, and integration capability. Older systems were simply not designed with today's requirements in mind.

Moving forward

For all of the aforementioned reasons, we are encouraging you to carefully review your installed base of older Bently Nevada products, especially those in automatic shutdown applications, identify those that require upgrading, and migrate to our newer products. We have specialist engineering capability in key locations around the world to help you evaluate your currently-installed systems and to recommend the best course of action to upgrade to a modern machinery protection and management system. Consider using our specialist engineering services to manage the complete upgrade as a turnkey project.

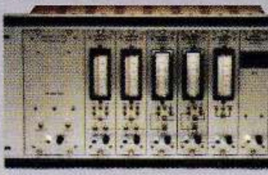
Please continue to look for future information in our ORBIT magazine on upcoming product obsolescence announcements and the status of products in the various stages of obsolescence.

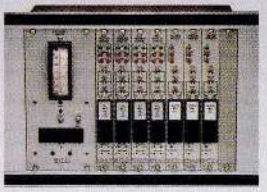
Update on 7200 and 9000 Series Machinery Protection System obsolescence

Bently Nevada's 7200 and 9000 Series Machinery Protection Systems were introduced to the market in 1975 and 1977, respectively. We're pleased that the quality and usefulness of our products mean that many of these systems are still providing reliable service. However, both of these products are in a formal obsolescence program - our ability to keep such systems operating reliably for you is limited, and will eventually go away. For this reason, it is important that those of you with an installed base of 7200 and/or 9000 Series Machinery Protection Systems develop a plan, if you have not already done so, for migrating to newer products. **We are encouraging you to carefully review your installed base of older Bently Nevada products, especially those in automatic shutdown applications, identify those that require upgrading, and migrate to our newer products.**

Our obsolescence program for these two products has been communicated extensively, via the ORBIT magazine and direct mailings. Briefly, we have used a phased approach to ensure that you could purchase complete new systems for a reasonable period of time. This first phase (availability of entire new systems) is followed by a period of availability of "spare parts only," and, finally, a phase during which we can only provide repair and refurbishment services but not entire spare monitor modules. Generally, each phase lasts approximately 3 years, allowing for a 9-year phase-out of significant product lines, such as the 7200 and 9000 Series. Indeed, to ensure we did not introduce unreasonable inconvenience, we have already extended our initial policy of providing new spare modules for 7200 Series through July 1999. This is a 36- month extension to our original plan, which has extended Phase 2 of 7200's obsolescence (spare parts only) to 6 full years.

For both of the 7200 and 9000 Series product lines, we are now in the phase of obsolescence where we can no longer provide spare modules. **As of 1 August 1999, we no longer provide spare modules for either 7200 or 9000 Series Systems.** We will provide repair and refurbishment of these systems through 2003, to the extent that parts are available from our suppliers. However, because the components used in these systems date back 20 years or more, our suppliers could discontinue availability of certain parts at any time, and with little or no advance notice. If you have not given thought to your installed base of 7200 or 9000 Systems, now is an excellent time to do so. Your Bently Nevada sales professional can help you structure a program for replacement of these older systems to ensure that your ability to protect and manage all your machinery continues without interruption.


7200 Series


9000 Series

condition where a valve is not in its correct position for a particular steady state load and operating mode.

Correlating valve position to vibration

Correlating valve position to vibration response can also be very useful, particularly on partial arc admission turbines. Depending on the sequence of valve openings, steam nozzle forces can lift the rotor within the bearing. This can lead to a fluid-induced instability if the centerline position of the rotor is near or equal to the geometric center of the bearing. Rotors operating at low eccentricity ratios also reduce the available bearing stiffness properties. This will cause higher levels of vibration with no change in the balance state of the turbine. You can use the correlation between opening valves, shaft centerline position, and vibration levels to adjust the valve opening sequence for more stable machine operation.

Conclusions

Valve position is a parameter that provides information about the turbine during all phases of its operation: startup, running, and shutdown. Valve position is related to the amount of turbine load while the generator is on-line; it is varied to maintain or change the load. Our 3500 Machinery Protection System can now provide the valve position measurement to our machinery management system to correlate with other machine critical measurements, such as load, temperature, pressure, or vibration. This can be useful in determining overall turbine efficiency and in identifying machine problems.

ANNOUNCEMENTS

Bently Nevada receives award from General Electric for excellent global support

Bently Nevada was one of only 180 vendors invited to the General Electric Power Systems Global Supplier Conference held in Atlanta, Georgia, 18-19 January 1999. As GE put it, "As one of our key suppliers, you have been invited to share in a two-day discussion of our changing market conditions and our new global sourcing strategy. A highlight for us on Monday is our awards banquet, where we will honor suppliers from across our GE businesses."

Five awards, one from each of the major GE divisions within Power Systems, were given to the companies with the most improved "Six Sigma scorecards." Six Sigma is the cornerstone of General Electric's long-term operating strategy. It is fundamentally a quality improvement program, but it also embraces delivery timeliness, cost reduction, and effective integration of the supplier with GE. The last award given that night, which we consider the most prestigious award, was to the company doing the best job working with all of the GE Power Generation business units worldwide. John Campi, GE's Sourcing Council Leader, presented the award for "Broadest Supplier Involvement" to Bently Nevada Corporation.

While Bently Nevada has received numerous accolades from customers over the years, virtually all of them have been for recognition of product quality, our quality management system, delivery timeliness, etc. In short, we have been frequently honored for the excellence of what we do in the factory. This award, by contrast, was a recognition of the excellence and the value of our global Sales and Service organization. We are proud to have received it, and are grateful to GE for the honor.

operating speed range. Smaller diameter rotors not only reduce mechanical losses, but, in the case of centrifugal compressors, allow the intake diameter of the stages to be smaller, thus increasing process work per stage.

Active control also makes perturbation testing practical. It allows designers to simulate certain operating conditions at the test stage to evaluate stresses, so that designs can be iterated, and confirms stability predictions using techniques such as root locus analysis. Active thrust bearings can be used to carry much higher static and dynamic thrust loads, such as seen during compressor surge.

Lubrication: Since the bearings use a hydrostatic instead of hydrodynamic lubrication system, the design is not limited to using traditional petroleum-based lubricants. Instead, materials that are more compatible with the process fluid or the environment can be used. This allows machines to have reduced or eliminated seal areas and to change the approach to processing soured lubricant.

Efficiency: Increased efficiency comes from the dynamic control of the rotor and from the changes in the seal system. Reduced vibration allows decreased seal and blade tip clearances, while reduced rotor diameters and use of hydrostatic thrust bearings decrease the shear (mechanical) losses. Reduced or eliminated seal areas greatly reduce the instability and mechanical losses associated with seals.

Benefits for end-users

The end-user can use the bearing to effectively control the rotor dynamics of his machinery, extending its life and helping meet market demands. It also provides a more comprehensive picture of the machinery condition, for more effective diagnostics.

Compensation: The active-control capability of the bearing allows for compensation of rotor-related problems until the fundamental cause can be determined and corrected. This reduces the need for unscheduled shutdowns and repairs, which are expensive. For example, the unbalance of a rotor due to process accumulations or erosion can be compensated, within the available active force range, until the unbalance can be corrected. The controller will provide the user with information about the magnitude of the unbalance force and its angular location relative to the Keyphasor® event. Knowing this and the force distribution on the rotor, the user can easily apply a precise balance correction with minimum downtime.

How BRDRC directly contributes to Bently Nevada products

Bently Rotor Dynamics Research Corporation (BRDRC) was founded in 1982 as a subsidiary of Bently Nevada Corporation. The primary objective of BRDRC is to expand the current body of knowledge on rotating machinery dynamics and machine malfunction diagnostic techniques. BRDRC's mechanical engineers and rotor dynamicists accomplish this by accumulating and evaluating existing knowledge from external sources and by developing new knowledge from internal research.

In their laboratories, BRDRC performs research and development functions on rotating machine dynamics. This often results in Bently Nevada product enhancements with improved performance and increased value. The ability of BRDRC engineers to design and prototype new products and provide mathematical analysis allows them to quickly turn theoretical ideas into reality.

BRDRC combines many disciplines within one group. Expertise is available in the areas of Electrical Engineering, Mechanical System Dynamics, Rotor Dynamics, System Modeling (Analytical and Experimental), Vibrations, Machinery Diagnostics, Modal Testing of Rotating and Non-rotating Structures, Software and Hardware Development (for rotating machine modeling and monitoring), and Signal Processing.

The laboratory facility permits in-house testing of prototypes under controlled conditions. Examples include:

- High-gain, narrow bandwidth filter.
- Lateral and torsional perturbation devices for rotor dynamic stiffness identification.
- Cracked shaft simulator.

The new Bently ServoFluid™ Control Bearing is one example of a product which BRDRC has helped to move from idea to reality. Although the thoughts for such a bearing originated many years earlier with Donald Bently, BRDRC personnel started prototyping and refining the invention in 1989. Today, this exciting product is ready for use in industrial applications.

production for up to ten years and plant it with grass to preserve land for future generations. These crops can be harvested without damage to the root structure and, therefore, continue to serve as a soil stabilizer, stream buffer, and wildlife habitat. Last year, Bently Biodynamics planted 50 acres of hybrid poplar trees and plans to plant additional acreage this spring.

Compost technology is a valuable tool being used to increase yields by farmers interested in sustainable agriculture. Several years ago, I consolidated my Nevada ranchlands, creating another business called Bently Agrowdynamics™. We started adding compost to soil, which substantially increased the yields and quality of the crops grown. A significant number of professional growers are discovering that compost-enriched soil can also help suppress diseases and ward off pests. These beneficial uses of compost can save growers money, reduce their use of pesticides, and conserve natural resources. Compost-enriched soil can also reduce erosion and nutrient runoff, alleviate soil compaction, control disease and pest infestation in plants, reduce pollution, and provide bioremediation, a new compost technology.

Bioremediation

Bioremediation is the degradation or stabilization of contaminants by microorganisms, for instance, bacteria, fungi, actinomycetes, and cyanobacteria. Each year, agricultural effluents, industrial residues, and industrial accidents contaminate surface waters, soils, air, streams, and reservoirs. Through bioremediation, Bently Biodynamics is able to restore contaminated soils, manage stormwater, control odors, and degrade volatile organic compounds.

Summary

Many of our customers are seeing themselves as "energy companies" with an interest in alternative energy sources rather than simply "oil companies" or "electricity companies." Bently Nevada is likewise responding to the challenges of a future that relies more heavily on renewable resources. Through the efforts of Bently Agrowdynamics and Bently Biodynamics, we are working to achieve environmentally and economically sustainable agricultural systems that help counter the effects of traditional fossil-fuel combustion.

ANNOUNCEMENTS

New offices –

Designed to promote team building

To better help you with all your service and support needs, Bently Nevada recently built new facilities for our Charlotte, North Carolina, and Baton Rouge, Louisiana, technical support centers. While these locations have been home to Bently Nevada regional sales and service personnel for many years, the new facilities' open floor plans enhance the ability of employees to interact with one another and work collaboratively. Large, multi-purpose classroom facilities are a part of both buildings' designs. It allows us to move training closer to our customers while providing a professional and controlled learning environment. Both of these facilities have also been designed and insulated for optimum energy conservation and are virtually maintenance-free.

Bently Nevada currently has over 80 technical support centers worldwide to help you protect and manage all your machinery.

Charlotte, North Carolina.

Baton Rouge, Louisiana.

Diagnostics: The control system provides knowledge of the actual forces acting on the machine. The end-user will be able to determine the changes in stiffness, which will allow a more accurate determination of the fundamental causes of faults and a more rapid field diagnosis. For example, two identical machines are used in the same process, and one has less rotor motion than the other. Typically, the one with less motion would be considered to be the healthier of the two. However, when the system forces and dynamic stiffness are determined, the machine with less motion is discovered to have the highest forces and the highest dynamic stiffness (restraints) of the two machines. This is typically seen in the case of piping strain or misalignment. In other words, the control bearing allows a Machine Specialist to determine malfunctions based on forces, which are the cause of rotor motion.

Perturbation testing: On-line perturbation testing while the machine is operating can provide the status of system rotor dynamic parameters and analysis of the machine's stability margin using Dynamic Stiffness and root locus analysis techniques.

Conclusions

We believe this evolutionary step in bearing design provides greater efficiency, reduced cost, improved control of rotor dynamics, and many other desirable qualities to both the designer and end-user. For additional information, contact, Marco Alcalde, Strategic Market Manager, at marco.alcalde@bently.com, or visit our website at www.bently.com/mktreference.htm.

References

1. Dowson, D., 1973, "Tribology before Columbus," *Mechanical Engineering*, Vol. 95, No. 4, pp. 12-20.
2. Muszynska, A. and Franklin, W. D., Bently, D.E., "Rotor Active 'Anti-Swirl' Control," *Journal of Vibration, Acoustics, Stress, and Reliability in Design, Transactions of the ASME,* April 1988, Vol.110, pp. 143-150.

What does active control of bearings provide that passive bearings cannot?

- On-line perturbation.
- Reduced sensitivity to changes in rotor forces or fluid parameters.
- On-line measurement of forces.
- On-line alignment adjustment.
- Compensation of rotor and fluid forces.
- Simulation of malfunctions.

On-line perturbation allows the machine user, designer, or diagnostician to input small amplitude, controlled forces to determine the modal characteristics of the machine, margin of stability, and response linearity. By closing the loop around the bearing, the machine becomes less sensitive to changing conditions of load, temperature, pressure, and flow.

Real-time active control allows the user to measure the forces that the control system compensates for, thus creating another useful tool to diagnose machine malfunctions, and to determine the actual health of the machine. For example, you have two identical machines under equal loads, and the vibration on Machine A is less than that of Machine B. The inclination is to say that Machine A is the healthier of the two. However, if you are measuring the forces, Machine A may be responding to higher forces than B, but the response is being limited by higher dynamic restraints. These higher forces could correspond to higher stress on the machine.

Active control of machine motion allows the user to adjust alignment of the machine, within the bearing and seal clearances, to determine the most stable or efficient operating point for the machine. On-line control can compensate for large, instantaneous changes in load caused by fluid process changes or unbalance, which could cause problems before an operator would have a chance to respond.

Using on-line perturbation, machine malfunctions can be simulated for testing or teaching purposes using force inputs of a certain frequency. The malfunctions could include misalignment, rotor-to-stator rub, fluid-induced instabilities, and cracked shaft.

Let's talk a bit more about the first part of the statement – "Helping you..."

Riggs: I think the key here is the tremendous flexibility that Bently Nevada has developed, which allows our customers the freedom to determine exactly how much and what type of "Help" they want. For customers who have determined that the selection, installation, operation, maintenance, etc., of the machinery protection and management systems is something that they want as a core competency, we have a comprehensive curriculum of training courses on everything from gapping probes to optimizing a Decision Support™ system (Machine Condition Manager™ 2000). For customers who have decided that, while machinery protection and management is a critical task, it is not something they need as a core competency, Bently Nevada can be a complete turnkey systems supplier, handling all aspects of system engineering, selection, installation, and optimization. We can be responsible for long-term system maintenance as well as supplying the mechanical engineering expertise to manage the rotating and reciprocating machinery. We can integrate our systems with other systems and can provide support for networked systems. We can work with the machine manufacturer to help them provide remote machinery diagnostics/management support – or just about anything in between.

> *"We have focused so intensely on "high-speed critical machine" understanding and product development in the past that all of the good work we have done with respect to reciprocating compressors, slower speed machines, rolling element bearings, etc., has been overwhelmed."*
>
> ***Steven W. Riggs,***
> *Senior Vice-President,*
> *Sales and Services*

Sabin: Customers aren't looking for suppliers to provide "components" anymore – they're looking for suppliers that can spec, deliver, install, integrate, and optimize a fully-functioning system – manage the whole project and provide a result, not just a box of hardware and software. Although not all customers are divesting themselves of the staff to provide project management, machinery diagnostics, or day-to-day data collection and machinery management tasks – many are. It is an absolutely perfect opportunity for us to increase the scope of what we provide to customers. It's a case of our core competencies matching up with their exact needs for services. The timing couldn't be better.

> *"Very simply, a "minimum system" used to be transducers and monitors, but now it is being redefined. "Minimum system" now means transducers, monitors, and on-line software."*
>
> ***Steven W. Riggs,***
> *Senior Vice-President,*
> *Sales and Services*

Steven W. Riggs,
Senior Vice-President, Sales and Services

Are we actually doing this or just talking about it/preparing for it?

Riggs: In this decade, we have completed 23 million USD in projects in North America alone – projects that all included selection of protection systems, system design, installation, commissioning, and training the end-users. Many of the projects also included system integration with control and information systems, optimization of the system, and remote or on-site diagnostics support. We have long-term system management support contracts with several customers.

Note*: A more detailed look at our engineering services capabilities, with specific examples, will appear in the next issue of the ORBIT.*

Chapman: We are investing heavily in providing new tools for our people to provide better service at lower cost. Our culture has been focused around manufacturing. We are implementing SAP's R/3 Enterprise Resource Planning system with an overall service business model. Our existing business system is MRP2-based, which will become a subset of the new model. Providing world-class global customer service is the direction we are heading.

We know we can do it because of our world-class attainment of MRP2.

Is service a core competency of Bently Nevada?

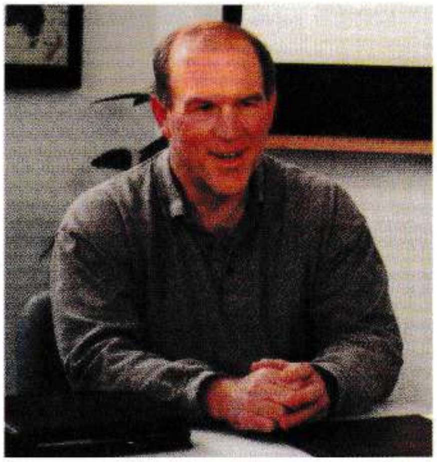
Chapman: Absolutely. We have people all over the world who spend more of their time at customer sites than in our own offices. We are quite proud of our people and their attitudes toward helping customers achieve their objectives. In many cases, we have become an integral part of their organizations.

> *"...System 1 is a platform that Bently Nevada can build on for the next decade."*
>
> ***Randall R. Chitwood,***
> *Vice-President, Engineering*

Riggs: It's more than a core competency – service is part of our corporate culture founded on our core value of "care of our customers." Service has been an integral part of BNC since the beginning. Don Bently personally provided much of that early support service, both for products and machinery diagnostics. He set a standard and an example that we continue to follow today. BNC has a bias towards service. We are very proud of the Control magazine Readers' Choice Awards we have received every year since their inception. In 1999, we received 77% of the vote.

Let's move now to another part of the mission statement, "...*all* your machinery." What is the significance of the "little red *all*" in our mission statement?

Riggs: The market's perception that we're only focused on "the big machines" is, in part, a result of our success – success with protection and management systems for high-speed critical machines with fluid-film bearings. We have focused so intensely on "high-speed critical machine" understanding and product development in the past that all of the good work we have done with respect to reciprocating compressors, slower speed machines, rolling element bearings, etc., has been overwhelmed. Of course, we have supplied plantwide systems, which have included protection and management for all types of rotating and reciprocating machines, in hundreds of different installations. However, for many customers, we are so closely associated with superior products, services, and methodologies for big, high-speed machines that they simply do not recognize us as having capabilities beyond that. The "little red *all*" on our cards is a reminder to keep the whole plant in mind, not just what we have become famous for.



Randall R. Chitwood,
Vice-President, Engineering

> *"Our customers need the equivalent of Microsoft® Office for their machinery."*
>
> ***Randall R. Chitwood,***
> *Vice-President, Engineering*

Chitwood: The "little red *all*" is also an effort to get the word out about our existing products like REBAM®, the Dynamic Power Transducer, and Trendmaster® 2000, to name a few.

> *"Shortly after initial release of our System 1 software, we'll be adding total and seamless integration of this Decision Support™ functionality – and, we intend to do it for all machinery – not just our traditional emphasis on turbomachinery."*
>
> ***Randall R. Chitwood,***
> *Vice-President, Engineering*

Sabin: The market opportunities for a company that can really do "*all*" machinery through an integrated product line is huge. Customers clearly need and want an integrated tool.

Chapman: Customers not only want to select a single vendor for particular types of products, they also want to do business with companies willing to take on considerably more scope. We are responding to that in many ways,

> *"...we make the world's best on-line machinery management systems – no exceptions."*
>
> ***Randall R. Chitwood,***
> *Vice-President, Engineering*

from more types of engineering services to developing new products, to supplying third-party devices. We are expanding our "comfort zone" to make things simpler for our customers.

> *"Customers aren't looking for suppliers to provide "components" anymore – they're looking for suppliers that can spec, deliver, install, integrate, and optimize a fully-functioning system – manage the whole project and provide a result, not just a box of hardware and software."*
>
> ***Steven J. Sabin,***
> *Corporate Marketing Manager*

How is the "little red *all*" specifically affecting engineering?

Chitwood: At Bently Nevada, we have dramatically increased our annual investment in Product Development over the past 3 years. Much of this investment is directly solving needs not normally associated with our "traditional" market. Beginning this fall with the release of the System 1™ software and our newest portable diagnostic and data collection device, Snapshot™ for Windows® CE, our customers should expect strong product support for all of their machines. And the engineers? They are excited about these new products and the value they will provide. I fully expect System 1 to be the "killer application" for asset management for several years.

How does our competence at building probes/monitors translate to what is being developed for "all your machinery" – software and portable instruments, for example?

Chitwood: We have a staff of very experienced electronics, mechanical, and software engineers. We are really very good at producing world-class products in a timely manner.

Chapman: Manufacturing is a core competence at Bently Nevada as well. Because we manufacture all of our products, we are able to integrate test engineers and process engineers right into the design teams. Having outstanding manufacturing team members next to the design engineers is mandatory to design and manufacture the products our customers expect from Bently Nevada for all of their machinery.

> *"Much of our mission reflects exactly what we've been hearing from customers: 'Help us by providing more services; address all our machines – not just a few; and teach us how to be proactive by managing our machinery, not just protecting it.'"*
>
> ***Steven J. Sabin,***
> *Corporate Marketing Manager*

Chitwood: We know it is equally important to build the right products with the right features. To make sure we get this right, we involve our research (BRDRC) and service groups in our product definition process. After all, they are users of many of our products. We have also added a definition phase that puts our design teams in direct contact with our best customers.

Steven J. Sabin, Corporate Marketing Manager

This is to assure that our designers really understand our customers' needs and business processes.

Why is System 1 such a significant part of the "little red *all*"?

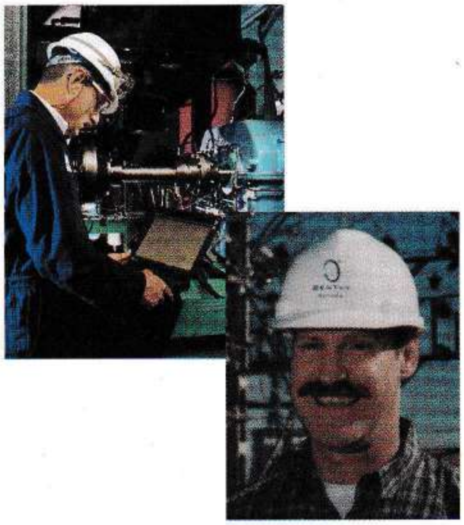
Chitwood: Our customers need the equivalent of Microsoft® Office for their machinery. The real power of MS Office is its integration. It allows users to use the right tool and makes it easy to have all of the tools. This integration not only makes the tools easy to use, but also helps us develop them. System 1 is a platform that Bently Nevada can build on for the next decade. It integrates all of our current functionality into a single framework. This framework will allow us to "snap" wide functionality into it via modular components. Initial release will support our new Snapshot™ for Windows® CE portable data collector. The next releases will rapidly focus on supporting some of our best data acquisition devices – such as TDXnet – with other functionality & hardware support occurring every year.

Pretty ambitious – what makes you think Bently Nevada can succeed?

Chitwood: Well, to start with, we make the world's best on-line machin-

How do you manage machinery?

(Glad you asked!)



- Project Management
- System Integration Engineering
- Cabinet Design and Fabrication
- Transducer Installation and Mounting Design
- Complete Mobile Machining Capabilities
- Electrical and Mechanical Site Supervision
- System Testing
- Predictive Maintenance Program Design and Implementation
- Training
- Risk Assessment
- Specification Consulting
- Machinery Diagnostic Expertise

You're in business to make products. When anything jeopardizes production, it gets your attention in a hurry. Sure, you've invested in reliable process control systems that help you manage your process. Unfortunately, that's only half the battle – your process is only as reliable as the machinery that makes it run. To ensure truly reliable production, you need to manage your machinery just as proactively as you manage your process. For those who've discovered this secret, the payback is enormous and provides a genuine competitive advantage.

We can help.

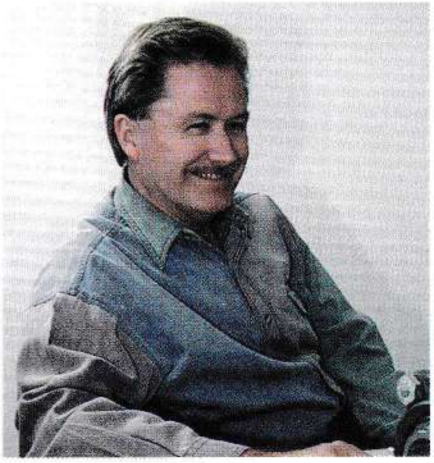
We're Bently Nevada and machinery management is our business. Imagine knowing as much about the condition of your machinery as you do about the condition of your process. Now imagine a company with the breadth and depth of services to make it a reality, yet manage the entire implementation as a turnkey project. With Bently Nevada, you don't just get a box of products and an instruction manual, you get a true *solution* from a company that can design, manage, integrate, optimize, and implement the entire project. We'll even assist in the economic evaluation to ensure we can achieve your return-on-investment criteria and, if outsourcing fits your business model, we can run the system for you on an ongoing basis.

To learn more about how our total scope of services can make it easy to begin managing your machinery, visit us on the world wide web at www.bently.com or contact one of our over 150 sales professionals today. You'll find us in more than 80 locations around the globe.

1(800) 227-5514 (USA only)
1(775) 782-3611

BENTLY
Nevada

HELPING YOU PROTECT AND MANAGE all YOUR MACHINERY®



Richard A. Chapman, Executive Vice-President / General Manager

each word in our mission statement is a powerful statement in itself. Our customers have come to expect direct, clear communications from us and openness and honesty in all of our dealings with them. Our mission statement, straightforward, clear, and tangible, is one more example of this aspect of our culture.

Where did it come from?

Chapman: It has evolved over time and we finally articulated it about five years ago in the succinct statement that appears on our business cards. We've found that expressing what we do in terms of "protection" and "management" communicates very well – both with customers and internally to the company. These categories work just as well for our hardware/software products as they do for our services.

What key initiatives and activities are being driven by the mission statement?

Chapman: Changing customer needs make it clear that it is no longer sufficient to only help, or to only protect, or to only manage, or to only focus on the vital few machines. A significant initiative in the Company at present is the integration of these capabilities into systems and services that work together more tightly. There are three other key initiatives that flow directly out of the words in the mission statement: First is "Helping you…." It conveys our substantial commitment to enhanced service offerings – to go beyond just installing and repairing our products by moving us into project management, system integration, turnkey machinery management, and other capabilities expected of an engineering services company. Second is "protect and manage." It speaks of the need for us to help customers manage their machinery, not just protect it. Third is "the little red *all*" that appears in our mission statement. It speaks of our drive to provide solutions for all classes of machinery in our customers' plants – small, large, critical, general-purpose, rotating, reciprocating – all of it.

> *"Changing customer needs make it clear that it is no longer sufficient to only help, or to only protect, or to only manage, or to only focus on the vital few machines."*
>
> ***Richard A. Chapman,***
> *Executive Vice-President,*
> *General Manager*

Riggs: Renaming the Machinery Diagnostics Services (MDS) department the Machinery Management Services (MMS) department is one example of the mission statement directly driving change within Bently Nevada. MDS had come to be synonymous with helping customers solve machinery problems after the problems surfaced – a reactive model of addressing machinery where the MDS engineer would travel to the site and analyze the problem with a portable tool, such as ADRE®. "Machinery Management,"on the other hand, is a proactive model. It focuses on managing machinery assets and knowing their condition at all times, primarily via online tools, with the engineer often located off-site.

Sabin: Marketing has an important – and fun – role in all of this: getting the message out. We are inherently the "mouthpiece" of the Company – we provide the communications to our own salesforce – getting them "fired up" about our products and initiatives. We also provide the communications to our customers – and perhaps even more importantly, from our customers. Much of our mission reflects exactly what we've been hearing from customers: "Help us by providing more services; address all our machines – not just a few; and teach us how to be proactive by managing our machinery, not just protecting it."

> *"Customers not only want to select a single vendor for particular types of products, they also want to do business with companies willing to take on considerably more scope."*
>
> ***Richard A. Chapman,***
> *Executive Vice-President,*
> *General Manager*

NEW PRODUCT

Active-control fluid bearings for a new generation of machines

by Donald E. Bently
Founder, Chairman, and CEO,
Bently Nevada Corporation, and
President,
Bently Rotor Dynamics Research
Corporation
e-mail: don@bently.com

John W. Grant
Principal Engineer
Bently Nevada Corporation
e-mail: john.grant@bently.com

Philip Hanifan
Manager, Machine Products
Bently Nevada Corporation
e-mail: phil.hanifan@bently.com

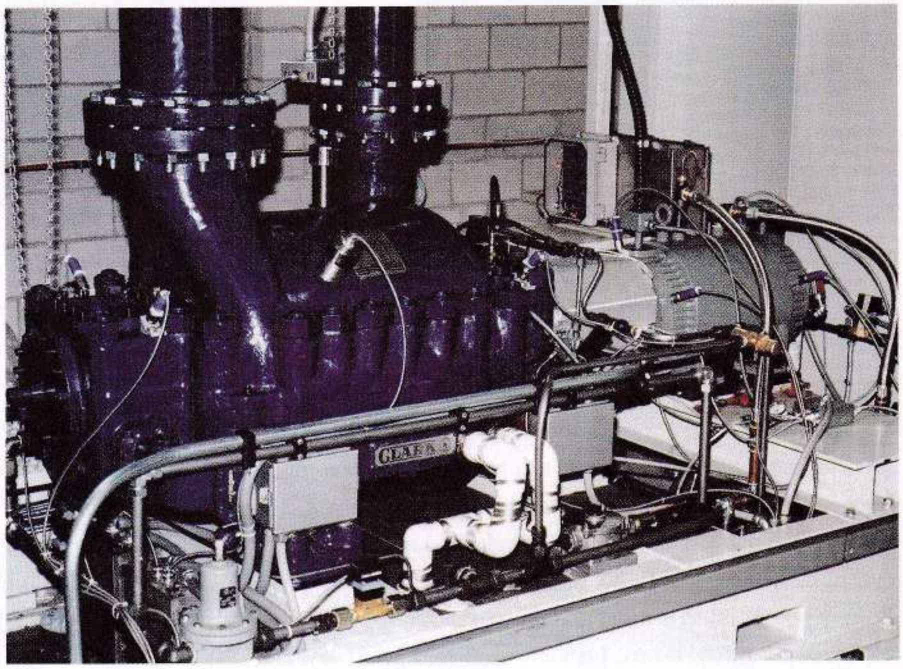


Figure 1. Current active-control bearing development platform.

Over the past 10 years, Bently Nevada Corporation and Bently Rotor Dynamics Research Corporation have been studying and developing an active-control fluid bearing for use in machinery with highly loaded bearings. The bearing uses the lubricant as a control fluid to compensate for rotor-related forces. This type of bearing offers OEMs and end-users design, operation, and diagnosis options that will result in a new generation of machines and more powerful machinery management capabilities. This bearing technology takes advantage of the positive attributes of fluid-film, rolling element, and magnetic bearings, while minimizing their negative aspects.

Four test machines have been used over the years to develop and test this technology. The current platform (Figure 1) consists of a Clark 1M6 compressor, with four of the six stages removed, directly driven by a 130 hp, 15,000 rpm, variable speed motor. The test units have used a variety of lubricants, such as water, water/glycol, and, currently, a Chevron light turbine oil (GST® ISO 32). Another full scale platform, in the construction phase, will also use water as a lubricant.

Bearing design

The Bently ServoFluid™ Control Bearing uses fluid forces to compensate for rotor-related forces. It consists of a hydrostatic (externally pressurized) bearing (Figure 2) which supports the rotor loads, position-sensing eddy current transducers, high-speed electrohydraulic valves, and a control system acting as a closed-loop system (Figure 3). The system was analyzed and designed using classical control theory techniques, including root locus analysis. See article on page 21. The radial hydrostatic bearing is a four-pocket design, and the thrust is a two-pocket design. Both have been designed with adequate pocket areas to perform active and static load support, and enough bearing surface to allow for fault conditions. The position sensors are standard Bently Nevada eddy current displacement probes mounted on either side of the

4. Limited speed due to the increasing centrifugal force, poor heat removal capability, and large element size.

In the late 1970s, magnetic bearings were introduced to rotating machinery. Magnetic bearings support the rotor by creating a magnetic field to attract the rotor. Typical configurations use various combinations of electromagnets and permanent magnets. See our article on page 26 for more about magnetic bearings.

In the late 1980s, Bently Nevada began developing active-control fluid bearings as an alternative to the design patches being done to the cylindrical bearing. Our earlier designs concentrated on both active "Antiswirl" control [2] and active radial pressurized control. The designs of the active radial bearings incorporated the positive features from previous bearing designs, while eliminating some of their problems. Both radial and thrust bearings can be active hydrostatic bearings or can be designed to provide combinations of radial and thrust support and control. The bearing configuration utilizes a high-pressure fluid bearing (hydrostatic lubrication). The rotor is supported by a combination of high-pressure fluid, which provides very stiff support, and controlled fluid forces applied to compensate rotor-related forces.

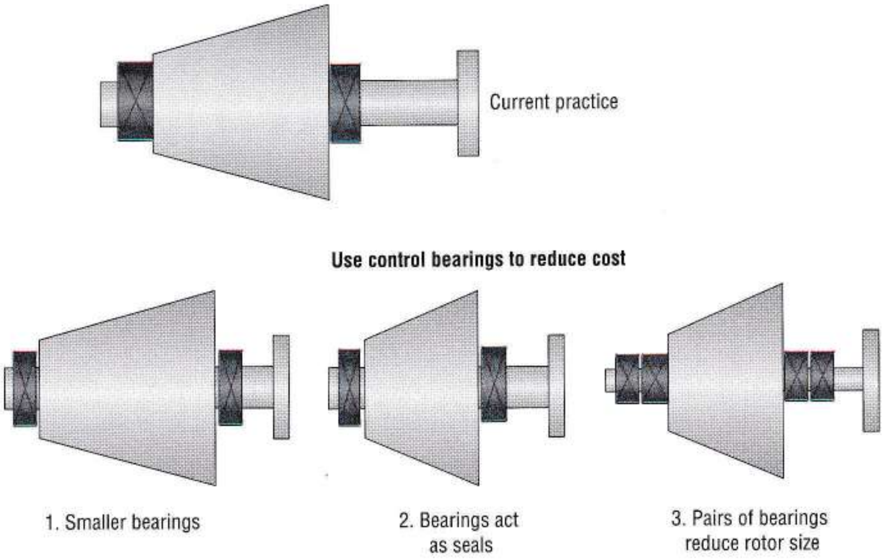

Current practice
Use control bearings to reduce cost
1. Smaller bearings
2. Bearings act as seals
3. Pairs of bearings reduce rotor size

Figure 4. Design benefits of ServoFluid™ Control Bearing technology.

Benefits of active-control fluid bearings include:

1. High load carrying capacity and reaction force magnitudes.
2. Smaller controller with low power levels.
3. Control fluid can be the same as the process fluid, or one that is easily separable or mixable, reducing or eliminating seals.
4. Fluid provides damping and dissipates heat.
5. Dual fault protection: with loss of control, the bearing is still an externally pressurized (hydrostatic) bearing; with loss of external pressure, the bearing acts as a normal fluid-film bearing.
6. Identification of forces, which are the cause of rotor motion.
7. On-line compensation of rotor-related force.
8. On-line adjustment of rotor alignment, within the clearance boundaries.
9. Rotor perturbation to identify rotor system parameters for machine diagnostics and prognostics.
10. Real-time control.
11. The same nonlinear characteristics as regular bearings, due to the noncompressible fluids, which get much stiffer at high eccentricity.

Bearing L/D history

About 50 years ago, bearings had larger length-to-diameter (L/D) ratios. This had the drawbacks of an increased susceptibility to fluid-induced instability and large mechanical shear losses. However, an important benefit the larger L/D provided was a counter moment effect, which stiffened the system and increased shaft resonance frequencies. Since then, there has been a trend to lower L/D ratios, which reduces the mechanical losses. However, by reducing the L/D ratio, the bearings have become more of a point influence, allowing the shaft modes to move lower in frequency. A more desirable effect would be to use pairs of bearings to create the counter moment. If the bearings are hydrostatic, the mechanical loss is reduced significantly and the stability is increased. If active-control bearings are used, the forces in each bearing can be controlled to create an active compensated moment on the shaft, thus stiffening the shaft and driving the rotor modes higher in frequency.

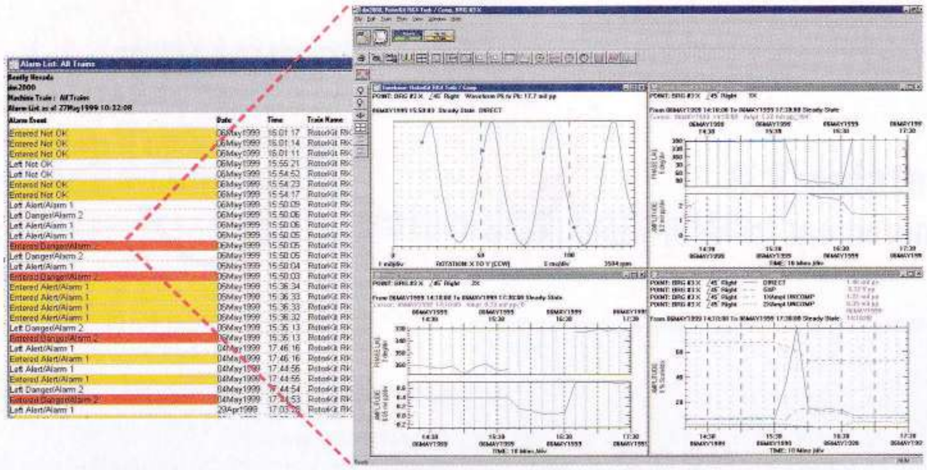


Figure 2. Clicking on an entry automatically launches specific plot types, saving time.

Better integration via OPC

This new version of DM2000 provides an *OPC Client* add-on module, to import process data. This allows any product that can act as an OPC Server, such as process control systems or historians, to serve process data to DM2000. Also, look for an OPC Server in the near future, which will allow the export of DM2000 static data.

Configurable "Quick View" option

To quickly assess key data, DM2000 can launch multiple plot types for a selected point with a single mouse-click. In the past, these plot types were fixed. With Version 3.0, however, you can select and configure which plots you want to launch when you select "Quick View" (Figure 1).

Plot launch from an alarm entry

Simply clicking on an entry in the active alarm list will now launch specific plot types, saving you keystrokes and time (Figure 2).

Configurable toolbar

Managing machinery often involves switching between related applications. With Data Manager 2000 version 3.0, you can assign actions, such as launching a third party program, to buttons on the toolbar (Figure 3).

More data labeling options

This new version of the software enables you to label Shaft Centerline, Acceptance Region, Trend, Multi-variable, and X versus Y plots in three ways: by *sample number*, rpm, or by date/time.

Enhanced Multi-user support

While DM2000 has always provided network support between data acquisition and display computers, or for exporting and importing data, it now supports a "true" network model for both display and configuration programs. These applications can now reside on a single, centralized server instead of on an individual user's hard drive. This enhancement provides a more efficient model for large systems and allows the customer's Information Services department to more easily maintain the network and the application.

More flexible trending

A *higher resolution trend interval* is now provided for up to 50 points in each system, allowing you to watch the behavior of important data even more closely.

More flexible alarming

Using DM2000 version 3.0 software, you can enable or disable software alarms *manually or automatically* during startup and shutdown events, which prevents spurious alarms.

More value with a Software Support Plan

These are just some of the significant enhancements we provided in Version 3.0. If you are an existing user of DM2000 with a software Technical Support Plan, you have already been advised of Version 3.0 and your eligibility to upgrade for free. If you're not currently enrolled in our software support plan for DM2000, you are missing out on free upgrades, just one of the many benefits you will receive. With several enhancement releases each year, the price of a Technical Support Plan is an excellent investment that has very tangible benefits.

For more information regarding this newest release of Data Manager 2000, or to learn more about our software Technical Support Plans, contact your nearest Bently Nevada sales or service professional.

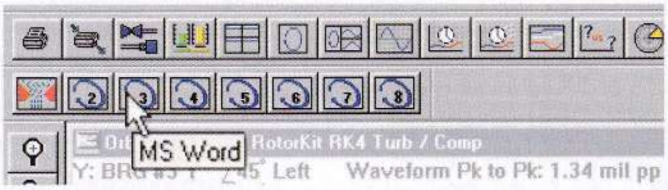
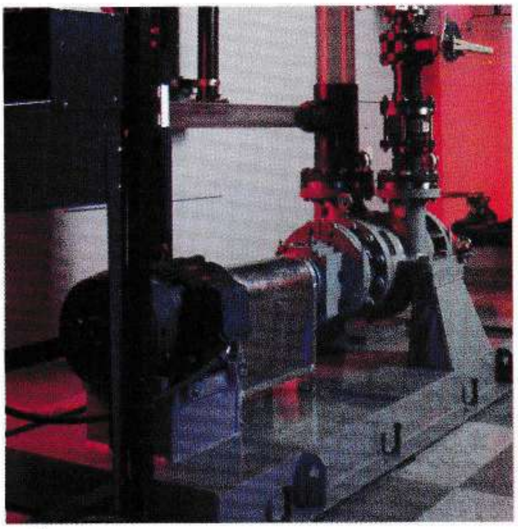
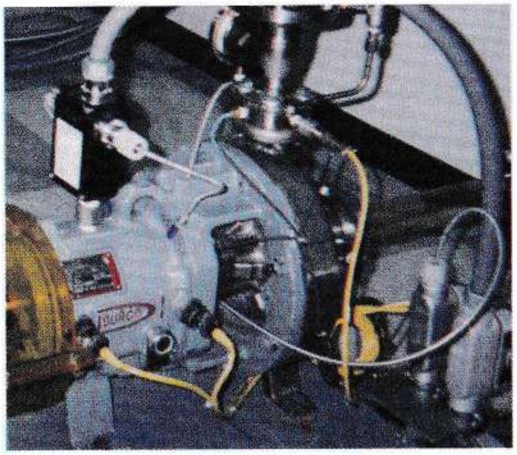


Figure 3. The enhanced toolbar lets you assign actions (such as launching third party software) to toolbar buttons.

The Flowserve Learning Resource Center

Learning is most effective when theory is followed by hands-on use of equipment. To put this philosophy into practice, Flowserve, one of the largest industrial pump, mechanical seal, and valve manufacturers, has constructed a modern, 24,000 square foot Learning Resource Center in Dallas, Texas. This Learning Resource Center consists of classrooms, Power Labs, Static Labs, and a Repair Lab. In addition to fully-operational pumps, valves, and mechanical seals, the four Power Labs are filled with training aids, such as clear flowmeters and piping, gauges, thermocouples, and vibration monitoring equipment. In the two Static Labs, there is a variety of different pumps, including two unique, clear, fully-operational pumps. The Repair Lab allows students to practice repairing equipment, while the Valve Flow Bench enables students to disassemble, overhaul, and test valves. This specially-designed equipment enables students to understand pump operation and learn how to identify the potential root causes of pump, seal, and control valve failures.





Bently Nevada transducer installation on pump in Power Lab.

The installed vibration monitoring equipment consists of Bently Nevada's Trendmaster® 2000 for Windows and vibration and process transducers. Bently Nevada's System Engineering Services organization provided the necessary expertise to select, design, install, and commission this system. It includes proximity, REBAM®, acceleration, Keyphasor®, pressure, dynamic power, and temperature transducers. The Trendmaster 2000 System automatically acquires data from these transducers using an on-line scanning architecture using TIMs (Transducer Interface Modules) and flexiTIM™ signal conditioners. This data is available for display and diagnostics, using plots such as orbit/timebase, full spectrum, spectrum waterfall, and current value. The Trendmaster 2000 data can be correlated with process condition measurements and exported to software, such as Microsoft Excel. Students access the Trendmaster Display Software at any one of seven workstations through a peer-to-peer network.

In the Power Labs, many of the pumps have been modified to allow students to compare maintenance methods. Eight of these pumps have been instrumented with XY proximity transducers at the outboard bearing and accelerometers on the pump and motor casing. Most have REBAM and Dynamic Power transducers installed. The Static Labs, which feature current equipment from many manufacturers worldwide, have two pumps instrumented with Bently Nevada transducers. A wide range of pumps, valves, seals, and instrumentation provide students with a chance to work with the equipment they will find in their everyday work environment.

Bently Nevada is pleased to be able to showcase the Trendmaster 2000 at Flowserve's Learning Resource Center. The participants at this innovative learning center will be able to see firsthand the features and benefits of our systems.

and vibration frequencies below this resonance. If the machine changes its resonance frequency due to changing process conditions (for example, rotating stall), the control system may become unstable. Because the control system may not have adequate force to maintain control, the machine may trip and suffer damage. Without feedback control schemes, the use of magnetic force to control the rotor is inherently unstable. Therefore, if any part of the closed-loop system is damaged, the unstable open-loop response allows excessive rotor motion that will trip and potentially damage the machine.

Additional problems and trade-offs

Some of the advantages claimed for magnetic bearings are that they are extremely reliable, do not need mechanical maintenance, consume very little energy, and continuously monitor the machine behavior. All of these claims have performance and reliability shortcomings.

- **Energy consumption**

  Let's review the claim that a magnetic bearing consumes very little energy. A particular bearing application requires a certain amount of power to support the load and react to dynamic changes. The amount of power required is usually the same, whether it is a fluid bearing or a magnetic bearing. A fluid-film bearing does require additional energy to overcome mechanical losses due to friction. However, this can be minimized by the use of a properly designed hydrostatic bearing.

  Therefore, the real comparison is between the additional electrical energy needed by the active magnetic bearing to support the rotor and dynamic forces, versus the energy used by pumps that provide fluid force for the hydrostatic bearing to support the load. In some cases, active magnetic bearings may reduce the power required for support and control by not controlling the real-time rotating forces in the machine: the unbalance forces or forcing components that are multiples of running speed. The softness of the bearing allows the rotor to simply seek out and rotate around its own mass centerline. If the unbalance is large enough, resulting in a large difference between the rotor's mass centerline and its geometric centerline, the rotor will contact the seals and/or bearing surfaces.

> *"When users have tried to reduce maintenance costs by installing magnetic bearings, some have actually experienced more unplanned shutdowns and increased operating costs."*

- **Diagnostic capabilities**

  Although the active magnetic bearing's electronic control system provides motion feedback signals, there is typically little or no capability to use the system for machinery diagnostic purposes. If the controller is not controlling the actual dynamic motion of the rotor, there is no information about the dynamic forces acting on the machine, nor the ability to perturb the system to determine the mechanical characteristics and stability. This type of active magnetic bearing cannot take full advantage of the benefits of active control.

- **Experience**

  Finally, there is the human factor. There is no depth of experience that maintenance people can call upon to help them evaluate the condition of the machine when using magnetic bearings. Until more experience is gained, the try and retry approach to machinery maintenance will be practiced.

One unintended benefit of the active magnetic bearing, though, has been to introduce the need to understand the Dynamic Stiffness properties of the rotor system – the machine's force-to-motion transfer characteristics or dynamic restraints. However, getting a magnetic bearing manufacturer to clearly state the Dynamic Stiffness properties can be very difficult.

Conclusions

Active magnetic bearings have serious weaknesses that limit their success. In some cases, they are not as good as current technology, and have not met manufacturers' promises or users' expectations. The magnetic bearing industry has seen many players come and go. These companies have installed magnetic bearings, tried to make them work, become disillusioned, and dropped out after suffering failure. The active magnetic bearing technology and industry lack the robustness required by users.

However, there *is* a vastly improved answer that provides exceptional performance. The new Bently Nevada active-control fluid bearing includes clearly stated performance specifications that are determined by dynamic control theory. This bearing will revolutionize machine design and operation throughout the world. See our article on the ServoFluid™ Control Bearing on page 15.

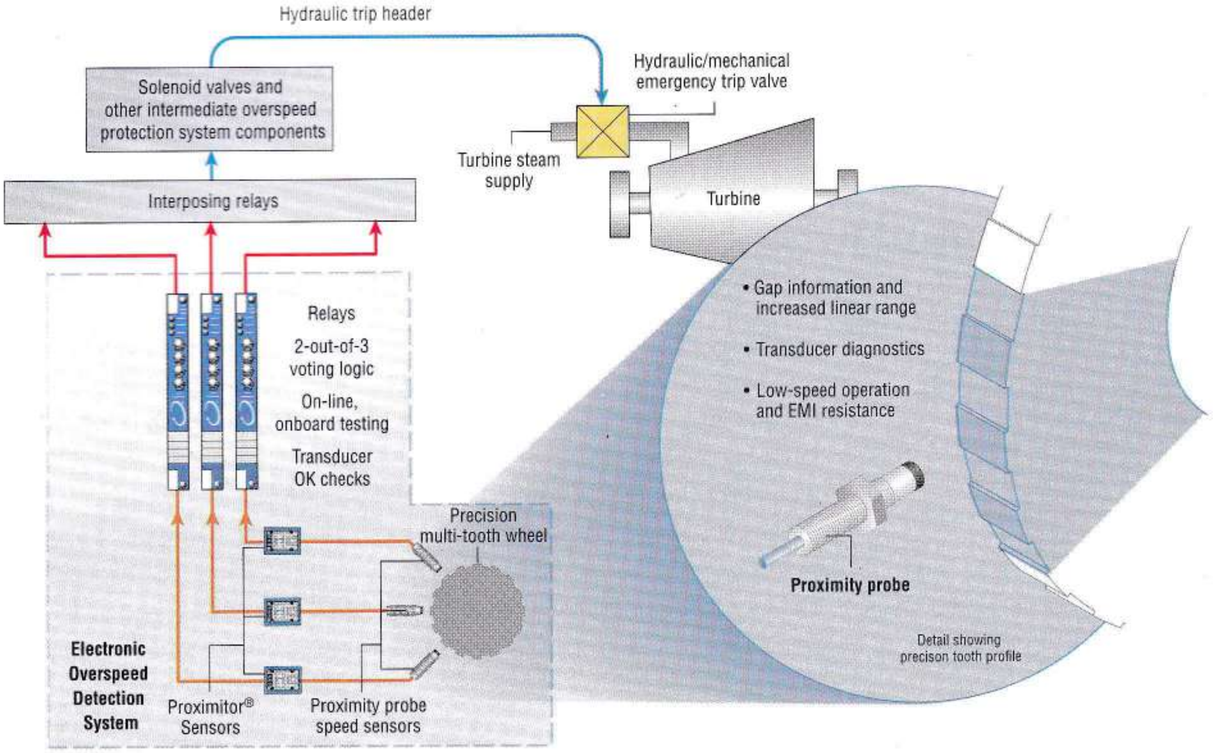

Hydraulic trip header
Solenoid valves and other intermediate overspeed protection system components
Hydraulic/mechanical emergency trip valve
Turbine steam supply
Turbine
Interposing relays
Relays
2-out-of-3 voting logic
On-line, onboard testing
Transducer OK checks
• Gap information and increased linear range
• Transducer diagnostics
• Low-speed operation and EMI resistance
Precision multi-tooth wheel
Proximity probe
Detail showing precison tooth profile
Electronic Overspeed Detection System
Proximitor® Sensors
Proximity probe speed sensors

Figure 1. Electronic Overspeed Detection System using a proximity probe transducer system.

wiring fault diagnostics.

- Much longer linear range.

  The 80 mil effective linear range of a standard eddy current transducer is far greater than the typical 30 mil nonlinear range of magnetic pickups. This increased range also offers more of a buffer between the sensor tip and the rotating gear teeth. For machines with over 5 mils of mechanical runout or vibration, maintaining proper clearance can be a problem if magnetic pickups are used.
- Greater bandwidth when using longer cable lengths.
- Less susceptibility to EMI (electromagnetic interference).
- Interchangeability with vibration, position, and Keyphasor® transducers, reducing spare part requirements.

Components or solutions?

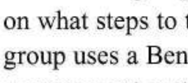
An electronic overspeed detection system is merely one component in a complete overspeed protection system. The system must be viewed in its entirety with considerations given to valve response times, steam piping lengths (for steam turbines), process shutdown interlocks, as well as machine trips and rotor acceleration rates. It requires a capable engineering consultant and system integrator, not just a parts vendor.

This extremely critical machinery protection function is often considered a safety-related system by many customers because an overspeed event means not just a process interruption and a broken machine, but a catastrophic failure that can release energy and threaten lives. It is absolutely essential that a qualified system integrator with experience in overspeed protection system design, installation, integration, and testing be used to ensure the system works properly and prevents the machine from ever being able to accelerate beyond maximum permissible rotational speeds, even during upset conditions, such as a coupling failure. For this reason, it is important to approach an overspeed system as *an engineered system* that requires the services of a skilled engineering consulting firm. Bently Nevada has this skill and experience to provide not just the transducers and protective monitors, but also the installation, engineering, and integration expertise to ensure you get a system that works as intended and is properly designed and installed. We can manage the entire project for you and can even provide services to perform periodic testing of the system as required by your insurer or safety regulations.

For more information, please visit our website – **www.bently.com/mktreference.htm** – or contact your nearest Bently Nevada sales or service professional.

Bently Nevada systems don't cost ... they pay

A U.S. petrochemical facility connected its Bently Nevada machinery protection system to its Distributed Control System (DCS). If one of their machines experiences high vibration amplitudes, the Operators are alerted to this through the DCS, and they contact the mechanical group for decision-making on what steps to take. The mechanical group uses a Bently Nevada machinery management system to analyze the problem, and take action if needed. An example of this took place when the 4th stage of the charge gas compressor experienced high vibration amplitudes. The Bently Nevada Decision Support™ "expert" system diagnosed the problem as an instability due to fluid whirl, and the orbit plot displayed by the system confirmed this. By adjusting the process and cooling the 4th stage case, the customer was able to keep the ethylene unit running a few more weeks until their scheduled outage. According to the customer, **this saved approximately USD 2,500,000 in production.**



A Brazilian refinery was experiencing broken shafts, impeller damage, and heavily damaged bearings approximately every two months on three turbine-driven pumps used to remove the fluid left in the bottom of a cracking tower. The only feedback Operators had was the flow level in the header and the fluid level in the cracking tower. Pumping requirements were handled by two of the three pumps, with the last one used as a spare. After the installation of a Bently Nevada machinery management system, Operators noticed that, during specific process conditions, the pumps began to vibrate excessively. The Operator called Maintenance and asked them to investigate. Maintenance personnel logged onto the Bently Nevada system from their desk and discovered that most of the vibration was at the pump blade passing frequency. They concluded that the problem was probably caused by a lack of flow. Further evaluation revealed that load was never equally distributed between the two pumps they were using. Suspecting unequal flow distribution, Operators varied the pump speed via the turbines and were able to reduce overall vibration. Even though the Operator did not look at dynamic data during this operation, maintenance personnel reviewed the machinery management system's plots and confirmed that the fundamental cause was poor flow management. The customer reports that the pumps have been in operation for 16 months now, with no reported failures. **The result is savings of over USD 100,000.** When this savings is added to other savings from averted failures, the machinery management system has paid for itself several times over.

Almost immediately after installation, a Bently Nevada machinery management system played a key role in preventing a 7 to 10 day shutdown at a U.S. petrochemical facility. The particular incident involved a coupling attaching a 7000 hp ac synchronous motor to a twin-screw extrusion unit. Just nine days after the machinery management system was turned on, vibration increased to the Alert level. Nine days later, it increased to the Danger level, calling for immediate action. With access to strategic information via modem, management was quickly able to identify the problem and made the decision to open the machine and remove the coupling. Three of the six coupling hub retainer bolts had broken, and the remaining three bolts had been sheared off. If there had been a failure, much more of the machine would have been damaged, which might have meant a bent or broken extruder shaft or motor shaft. **Either scenario would have cost the company in excess of USD 750,000.**

A South Korean cement manufacturer used a Bently Nevada machinery management system to identify significant bearing wear on the first stage of a kiln's main speed reducer. The system was credited with helping plant engineers identify the problem before the machinery failed, thereby allowing them to order a replacement part and schedule maintenance. They estimate this advance notice saved 24 hours of unscheduled downtime, **helping save USD 440,000 worth of production** that would otherwise have been lost. In the first year it was installed, the machinery management system was also instrumental in other machine saves and was credited with preventing 80 hours of unscheduled downtime, **saving the plant approximately USD 1,500,000 more.**

BENTLY Balance™ Balancing Software

by Bob Hayashida

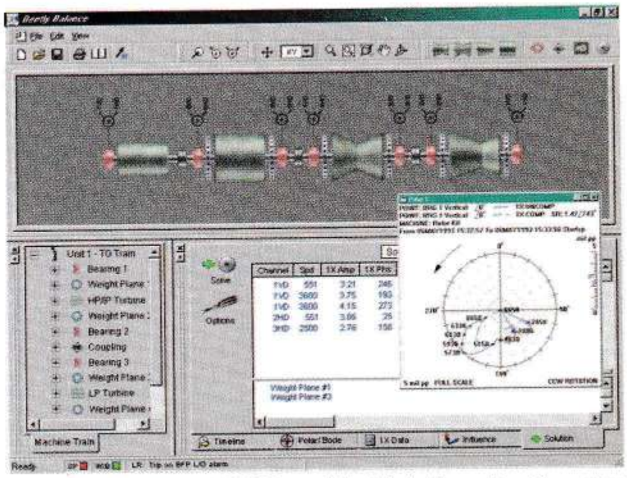
Principal Applications Engineer
Bently Nevada Corporation
e-mail: bob.hayashida@bently.com

Bently Nevada has been balancing rotating machinery for more than thirty years. In the early days, much of the balancing was done by hand, manually calculating influence and effect vectors and then plotting them graphically on paper. In the 70s, some of the first effective tools were developed for computer-assisted data reduction. These tools were also useful for balancing and evolved into the first ADRE® (Automated Diagnostics for Rotating Equipment) system.

In 1982, Bently Rotor Dynamics Research Corporation popularized the concepts of Dynamic Stiffness using forces, and stiffnesses to define the dynamic characteristics of the periodic motion of rotating machinery. These methods are now used worldwide to provide an effective methodology for balancing.

When it was released in the early 1990s, Bently Nevada's Multiplane Balancing Software filled an important need. It was a highly-intuitive software tool for dynamic balancing of rotors using up to 12 measurement planes and 12 correction planes.

We are now able to provide an even better software product – Bently BALANCE™ – to meet your needs and those of our own Machinery Management Services organization. Bently BALANCE software enables you to:



Channel	Spd	1X Amp	1X Phs
1VD	551	3.21	246
1VD	3600	3.75	193
1VD	3800	4.15	273
2HD	551	3.06	25
3HD	2500	2.76	156

Figure 1. Bently BALANCE graphical interface showing rotor module and response at bearing.

- *Automatically* import data from Bently Nevada's ADRE for Windows databases (auto-extraction support for other Bently Nevada software products is planned in the future as well).
- Use a modern and highly graphical user-interface.
- Perform "what if" scenarios and graphical balancing solutions with calculated polar plot responses.
- Calculate, use, and manage multiple Influence Vectors.
- Balance for multiple speeds, or a range of speeds, under different load conditions.
- Handle your most complex balancing requirements – up to 16 XY measurement planes and a virtually unlimited number of correction planes.
- Provide manual entry of data, so it can be used in any application where amplitude and phase measurements are available, regardless of the data source.
- Provide detailed documentation, a history of balancing activity, and the results.
- Enjoy full support for Microsoft® Windows operating systems.
- Have Year 2000-compliant software.

Since successful balancing involves more than just a software tool, Bently Nevada also provides on-site training and balancing services. Please see the article on page 53 for information about our on-site balancing courses. If you prefer to have Bently Nevada's professionals balance your machinery for you, contact your nearest Bently Nevada sales professional and ask about our Machinery Management Services. We can provide one-time balancing services or a complete machinery management services contract, which encompasses all aspects of machinery condition.

Bently BALANCE will be available in the 4th quarter of 1999. So, get ready! Whether you perform on-site field balancing, shop balancing, or both, we can hardly wait to put our new balancing software into *your* hands.

Differential Transformers) are the transducers of choice for measuring the position of a valve stem, based on the valve's full stroke length (Figure 1). Their only electrical components are coil windings, allowing them to be used in environments up to 149° C (300° F). They are sealed fairly well against contaminants and have good accuracy.

The 3500/45 Position Monitor drives the primary winding of the LVDT with an ac signal. It conditions the signals that appear on the two secondary windings and combines them to give an indication of linear position. The 3500/45 does this without requiring any intermediate components or converters. The position measurement will be displayed as % open or % closed, as configured by the user. The available full scale ranges are:

1 in (25mm) 2 in (51mm)
4 in (101mm) 6 in (152mm)
8 in (203mm) 10 in (254mm)
12 in (305mm) 20 in (508mm)

A rotary potentiometer is used to measure the rotational position of a camshaft, which controls the sequencing of several valves. There are different full-scale ranges of rotation, depending on the steam turbine's design. The 3500/45 Position Monitor now offers full-scale ranges from 50° to 300° of rotation, displayed in % open or % closed, as configured by the user.

The new 3500/45 Position Monitor provides four channels of valve position using either four AC LVDTs or four rotary potentiometers. Another highlight of the 3500/45 Position Monitor is the option to use an AC LVDT to obtain a case expansion measurement when the operating environment of the case expansion transducer is above 85° C (185° F), preventing the use of the DC LVDT.

Average valve position measurement is ambiguous

In addition to needing to know the position of various individual steam valves, some customers have requested an average valve position measurement. They average the governor valve % openings to give an overall % of effective steam flow, which is related to load. This is really an average only if the mode of operation is "single valve" (all governor valves opening in unison) or if the mode is sequential and there is a linear relationship between the position of each valve and the overall percentage of flow.

However, the sequential mode relationship generally is not linear, thus the operator still must interpret the meaning of the average with respect to the steam flow. Even if the relationship between sequential valve opening and effective steam flow was linear or the mode of operation was single valve, knowing the average would not necessarily be that valuable. If a faulty valve is not opening when it should, the turbine control system opens the remaining governor valves to maintain the load. The average would still read the same as if the faulty valve were operating correctly. You would not know that there was a problem with the valve until other, more serious, problems presented themselves, such as unbalance of casing temperatures, casing distortion, increased thermal fatigue damage, or even a rub condition. Therefore, each individual valve opening should be known, not just an average or effective steam flow.

Correlating each valve's position to load is more meaningful

Comparing valve position to load over time will provide an indication of changing turbine efficiency or machine problems. Specifically, equating an individual valve's position to load is more valuable than averaging the valve positions, especially when operating in the sequential valve mode. With the new 3500/45 Position Monitor options for valve position and with the new System 1 machine management software (see article, page 33), you will be able to set alarms for each valve's position based on its relationship to load. The load measurement could be obtained using a 3500 Process Variable Monitor.

For example, Figure 2 shows the opening sequence of the eight governor valves displayed in % open for each valve versus the % of full load of the unit. Based on the data, you could set software "under alarms" for governor valves 1 to 4, 5, and 6, based on the % of full load (MW). The logic that could be incorporated might be: If the load is greater than 90% of full load and governor valves 1 to 4, 5, or 6 are less than 98% open, then alarm. Thus, the operator would be forced to acknowledge the

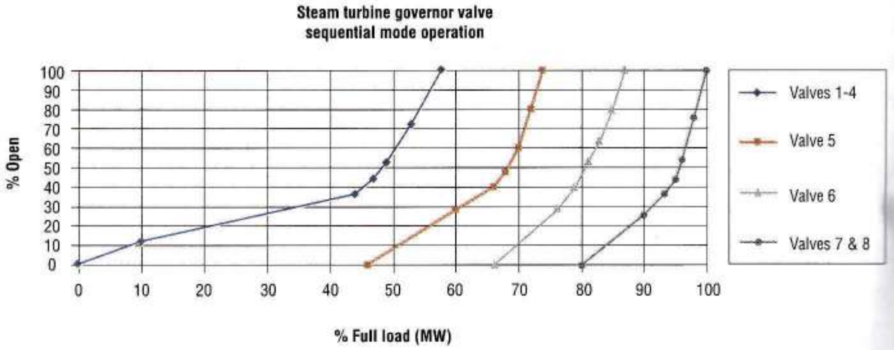


Figure 2. Opening sequence of governor valves versus load.

ery management systems – no exceptions. We are able to process many parallel high-speed transducers and cost-effectively get this data to our Decision Support™ product, Machine Condition Manager™ 2000, or to an engineer located anywhere in the world. There are some other on-line and off-line products out there that try to compete with our Data Manager® 2000, but we are the standard that others are measured against. We have already solved the toughest engineering problems associated with the on-line system. Now we are working towards expanding to include off-line functions like Snapshot™ for Windows® CE, and on-line data that doesn't require such high-speed acquisition, such as data from Trendmaster 2000 or Performance Manager™ 2000. We also have global development resources located in technical centers around the world. For example, we take great pride in our software development team in Mumbai, India. These engineers are very professional, quality-oriented, and great to work with. India has a strong core competence in software engineering, and we have been doing successful development there for almost 10 years.

Let's switch gears once again and talk about the remaining phrase in the mission statement – "Protect AND Manage."

Chapman: This is basically an educational issue – getting the message out about the new "rules" for our customers to get – and stay – competitive. Protection alone is not enough.

Sabin: The little word "and" - our mission talks about protecting *and* managing your machinery – has been a challenging message to deliver. In some ways, we've been victim to our own success. We are recognized as being very, very good at providing transducers and monitors for protecting machinery and teaching the world that protecting machinery is necessary. Unfortunately, some people think that is *all* that we do. Now, however, we have to bring another message: protection is necessary, but not sufficient – you must also manage your machinery.

Not everyone will be familiar with the terminology "machinery management." Could you elaborate?

Sabin: Some people call it "condition monitoring," others "predictive maintenance," still others have different names. At Bently Nevada, we use the term "machinery management." The basic idea, is that, whatever you call it, you use software products to trend data and reduce it into meaningful information, so that you can proactively understand your machine's condition at all times and make informed operating and maintenance decisions.

This goes beyond just basic vibration data - it includes detailed rotor data like 1X amplitude and phase, shaft radial position, NOT 1X data, 2X amplitude and phase, and other parameters. Process data needs to be included as well, so you can correlate it with machinery information and understand the interaction. Finally, machinery management goes beyond just the data – it involves the use of embedded intelligence to reduce the data into actionable information™. We call these Decision Support™ systems, and they are very important if you don't want to waste time reviewing data on good machines. It's the 80/20 Rule.

Note: *see the article on Pareto on page 49 for more information on the 80/20 Rule.*

Good managers anticipate and direct things toward a desired result – they don't just sit back with a hands-off approach and let things go where they may. Machinery management is analogous. As important as they are, our protection systems don't really act until they are called upon to protect the machine – after an alarm level has already been violated. Our machinery management systems, on the other hand, let you take action long before an alert light on the monitor comes on. Our president, Roger Harker, refers to this as "managing below the alert level." I like that. It's a great phrase to succinctly capture what we're doing.

Are you succeeding with this message, and have you been able to measure the success?

Riggs: Ten years ago, we were happy if 5% of protection systems were supplied with some type of on-line software system for machinery diagnostics/management. Today, that figure is approaching 40%, and it is growing. Very simply, a "minimum system" used to be transducers and monitors, but now it is being redefined. "Minimum system" now means transducers, monitors, and on-line software. We're also finding many customers that need to address general-purpose machinery want more than just a portable data collector – they also want an on-line environment to cover selected "non-critical" machines. The market demand for this is increasing as customers apply automation to a larger proportion of their process and machines. System 1 brings this all together under a single umbrella.

Sabin: The market itself has helped tremendously. Many of our end-user customers are in commodity businesses – gasoline, oil products, and electricity.

against stationary parts. In most cases, it would be better if the rotor was well-balanced, so that the mass centerline and geometric bearing/seal centerlines were coincident, and the machine had a well-made, stiff foundation, so that the structural motion could be minimized.

- **Power supplies that are operated at a reduced duty-cycle affect the control system's frequency response and limit the maximum shaft rotative speeds that can be controlled.**

  Heat reduction is sometimes attempted, bypassing lower duty power supplies for the active magnetic bearing electronics. This means that, for part of the rotation cycle, the control signal is off and the system's frequency response is reduced.

- **Fluid (gas or liquid) is often used to remove unwanted heat, which requires some type of delivery system.**

  Thus, the magnetic bearing promise of a "fluid-less bearing system" is often not realized in practice. Many machine users and OEMs are led to believe elevated reliability claims because active magnetic bearing technology does eliminate the lubrication system. This potentially provides a wear-free system, thus forecasting longer planned overhaul and maintenance intervals. However, by eliminating fluid lubrication, the ability to remove heat in the bearing regions is greatly reduced. There have been cases with active magnetic bearings where the flow of coolant gas (typically air) was not enough to control heat buildup, and water spray heads were needed to keep the active magnetic bearings from failing.

Weakness #2 – Limited fault protection

When a magnetic bearing control system fails for any reason, the rotor and stator of the active magnetic bearing could rub, causing extensive damage. Machines with active magnetic bearings always have auxiliary (sometimes called catcher or backup) bearings installed. Typically, these are rolling element bearings, and the clearance between the bearing's inner ring and the rotor is designed to be less than the active magnetic bearing clearance. The backup bearings create their own set of problems:

> *"Active magnetic bearings ... suffer from three significant, fundamental weaknesses."*

- **Placement of the backup bearings can change the machine's rotor dynamic behavior.**

  Some backup bearings are placed outboard of the active magnetic bearings, which changes the natural frequency of the rotor system when a fault occurs. Consequently, when shutting down the machine, the rotor's radial displacement may be greater than predicted at the seal or blade locations, resulting in rubs.

  Fluid bearings, in contrast, have the major benefit of inherently damping rotor motion (reducing vibration) during shutdowns. Therefore, the savings due to elimination of lube oil systems and their maintenance may be more than offset by the increased costs in other areas.

- **The backup bearing suffers extensive damage when the magnetic bearing fails and requires regular replacement.**

  The clearances between the rotor and inner ring of these bearings are, by design, quite large. When the active magnetic bearing control system fails, the backup bearing literally "catches" the rotor, but the rotor will often bounce around within the bearing clearance until it eventually settles down and the machine coasts to a stop. The backup bearings can only sustain a limited number of active magnetic bearing failures before they must be replaced.

Weakness #3 – Inadequate compensation force

A significant limitation of the active magnetic bearing is its relatively low compensation force, which is much less than a standard film bearing. Since the magnetic force is a function of the bearing gap, the problem compounds when the clearance has to be increased for the backup bearings. This can result in both design and operating problems.

- **The area of the active magnetic bearing must be large to support the load.**

  Magnetic bearings have significantly larger diameters and lengths than fluid bearings. The difference can be visualized by comparing the "stiffness density" (load carrying capability) for the two: 40 Newtons per square centimeter (60 psi) for the active magnetic bearing, but over 300 Newtons per square centimeter (450 psi) for a typical fluid film or fluid control bearing. Therefore, fluid-generated forces are the choice for highly loaded machines.

- **The control system may not provide adequate compensation during some machine and bearing malfunction conditions.**

  As with any control system, the lowest resonance in the closed-loop response limits the system use to rotor systems with rotative speeds

Why renewable resources are important to us and to our customers

by Donald E. Bently

Founder, Chairman, and CEO,
Bently Nevada Corporation, and
President,
Bently Rotor Dynamics Research
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Most of our customers are in the power generation or hydrocarbon processing industries, and many of them are seriously pursuing the concept of renewable resources. For example, the Chairman of the Board of a major international oil company recently promised investors that his company will not postpone projects in renewable energy. He made this promise, even though, at the time, his company was in a less favorable financial situation as a result of depressed oil prices and the economic slowdown in Asia. In addition to oil and gas, this company has clearly stated that other energy sources, renewable resources in particular, will be high on their list for investments.

In the future, this company expects alternate and renewable energy sources to make up a larger share of the company's business. This company expects renewable resources to provide between 5% and 10% of the world's energy within 25 years, and as much as 50% by 2050, depending on world energy scenarios.

This prominent company sees itself more broadly as an energy company, rather than simply an oil company. Other companies that have traditionally seen themselves as electric companies or oil companies are similarly recognizing that they are energy companies, providing energy to customers, regardless of the source.

Opportunities for the profitable use of renewable energy sources abound. Although machinery will continue to be part of delivering the world's energy for many years, nonrenewable energy resources, such as fossil-based fuels, are declining. Bently Nevada and our customers are exploring innovative ways to be good stewards of the world's energy resources through the application of renewable resource methods.

> *"The amount of carbon dioxide in the world's atmosphere is increasing approximately 1% per year, due to the burning of hydrocarbon fuels."*

Advantages of biomass & composting

One of my businesses, Bently Biodynamics, is researching biomass uses and has developed a composting system. Our goal is to work in harmony with nature's essential resources: air, water, sunlight, and soil. Biomass is plant material, either raw or processed, such as fast-growing trees and grasses, agricultural residues (rice straw, wheat straw, and corn stalks), and wood waste (sawdust and tree prunings).

Put another way, biomass is stored solar energy that can be converted to electricity or fuel. Increased use of biomass for energy could help reduce greenhouse gas emissions and dependence on fossil fuels. More than any other energy resource, biomass can simultaneously address a nation's energy, environmental, and economic needs.

Fossil fuels remove carbon that is stored underground and transfer it to the atmosphere. In a combustion system, biomass also releases carbon dioxide as it burns; but biomass needs carbon dioxide to grow, therefore creating a closed carbon cycle. In this cycle, there is a net reduction of carbon dioxide. In addition, substantial quantities of carbon can be captured in the soil through biomass root structures, creating a net carbon sink that would help improve the soil and increase crop yields. **The amount of carbon dioxide in the world's atmosphere is increasing approximately 1% per year, due to the burning of hydrocarbon fuels. While this is a form of fertilizer, eventually, at some level, it will harm the atmosphere.**

These soil improvements can also decrease the amount of land needed to meet the market demand for food. The extra land could be used to grow biomass crops that would, in turn, restore soil carbon, reduce erosion and chemical runoff, and enhance wildlife habitat. Biomass crops are the same kinds of crops that we now plant to protect fragile land under the Conservation Reserve Program. This U.S. Government program allows farmers to remove farmland from agricultural

NEW
PRODUCT

# snapSHOT™
for Windows® CE

One more reason to look to Bently Nevada for all your Machinery Management needs

by Brad Law

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Bently Nevada is no stranger to portable data collection. We've been providing handheld, route-based portable data collectors for over 15 years, beginning with our original Snapshot™ product and evolving to Snapshot™ II, Trendmaster®, Trendmaster FFT, and Snapshot™ Plus. During that time, we've learned much about the role of portable data collection and its importance in establishing a machinery management strategy that can reach every machine in your plant, not just "the big stuff." That's why our newest and most advanced portable data collection system – Snapshot™ for Windows® CE – is such an important part of our product line. It represents our commitment to "Helping you Protect and Manage ***all*** your Machinery®."

In many ways, Snapshot™ for Windows® CE is a continuation of everything we've learned in the past about portable data collection – what works, what doesn't. That's why we are continuing to use the Snapshot name – it tells you you're buying a product that is simply the latest version of a long line of Snapshot portable data collectors. However, our latest Snapshot is more than just "another data collector." It embodies advances in technology that simply weren't possible until recently: things like ultra-lightweight design, compact size, and extended battery life – not to mention the balance of performance, flexibility, and ease-of-use that its Microsoft Windows® CE operating system affords.

Armed with this advanced technology and our experience, we set out to make this Snapshot a superior portable data collector. We also did one more thing: we consulted the experts – you, our valued customers. With this in mind, we sent our design team into the field to perform one of the most thorough marketing and user-needs definition exercises Bently Nevada has ever undertaken. As a result, we understand what you need in a portable data collector.

Here's what you told us...

Must be easy to use...

Snapshot™ for Windows® CE is designed to serve the needs of both "surveillance" and "diagnostic" users.

For surveillance purposes, the user can simply and quickly collect dual channel vibration amplitude and phase data, temperature measurements, select observations from a list, and even type a note for recall later. Once the data has been collected and a problem requiring further investigation found, Snapshot provides the ability, with data displays, to help diagnose machinery problems. All relevant machinery data can be displayed on the instrument's integral touch-screen display. Data display formats include full and half spectrum, orbit and timebase, 1X and 2X vectors, Prime Spike and Rotor Region filtered data (valuable tools for monitoring rolling element bearing condition), and many others.

Must collect *all* the data needed to get the job done...

Many tasks *require* two channels plus phase to really find out what's wrong and deal with the root causes – not the symptoms – of mechanical failures. Few products on the market can actually deliver the required performance in a package that is small enough for everyday data collection needs, yet powerful enough to meet your most advanced diagnostic requirements for general-purpose machinery. Snapshot can. It

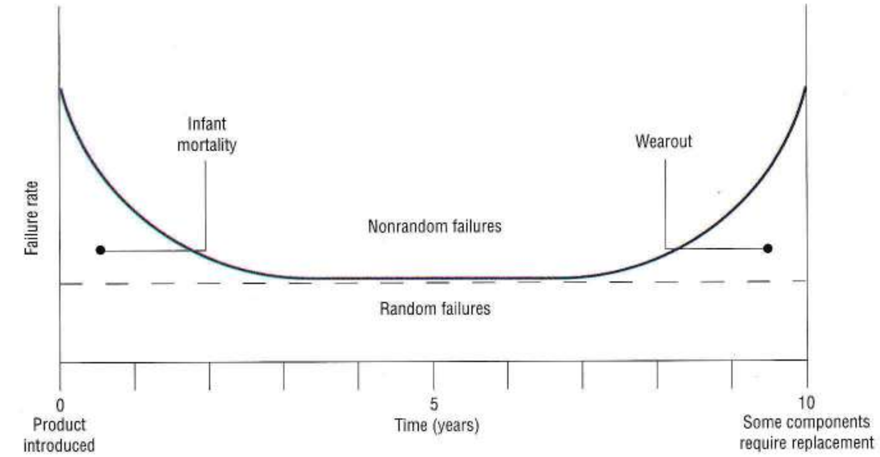


Figure 1. Typical reliability bathtub curve used to determine obsolescence policy for a product.

of my current system? Does the overall system architecture represent current best practices?" What was good enough in electronic products 25 years ago is simply not good enough today.

> *"In the past year alone, we have spent well in excess of $1,000,000 redesigning our products, mostly older products, because vendor parts have been made obsolete."*

The evolution of component failure understanding

In the early days of solid-state electronics, it was often thought that components, if they survived "infant mortality," would last indefinitely. We now know better. Many components, such as electrolytic capacitors, switches, and other mechanical parts, have finite life spans. The "bathtub curve" (Figure 1) is used to graphically display the likelihood of failure of an electronic component over time. While we cannot accurately define at what point in time the reliability of a component might begin to deteriorate, we do know that it happens. The possibility cannot be excluded that a failed component part could compromise the integrity of your machinery protection system.

The evolution of component availability

This concept is sometimes referred to as parts "de-proliferation." Whatever word is used, it means that parts which were once produced are no longer produced. This is nothing new, but the pace of "rationalization," particularly for older design parts, has definitely picked up. In most cases, we deal with this issue without you ever being aware of it. In the past year alone, we have spent well in excess of $1,000,000 redesigning our products, mostly older products, because vendor parts have been made obsolete. Sometimes, however, redesign is impractical or even impossible, and at that time we are forced to obsolete parts, or at least options. We want you to be aware that the older the product, the more likely it is that component parts will be made obsolete. There is an increasing probability that a time will come, possibly with no warning, that we will be unable to continue to produce, repair, or otherwise support that product.

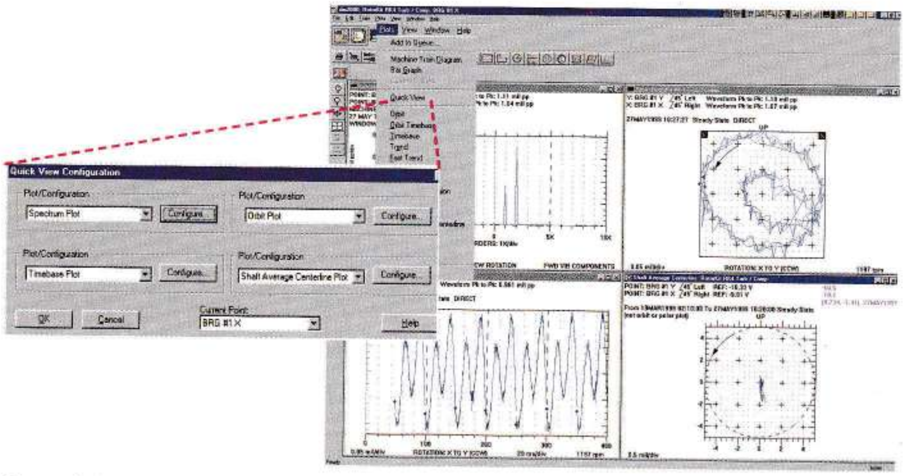
New Product Development is the lifeblood of any company, and Bently Nevada is certainly no exception. It is a competitive world, and we work very hard to continue to develop new products which offer you increasingly greater value. As newer product sales begin to displace sales of older products, the production cost (per unit) of the displaced product rises for a variety of reasons. Cost of spare parts, cost of repairs, and the timely availability of spares are all impacted negatively when this happens. This happened in the 1980's when sales of 3300 Monitoring Systems displaced sales of 7200 Series Monitoring Systems. It is happening now with sales of 3500 Protection Monitors displacing sales of 3300 Monitors.

The evolution of customer needs

"Machinery Management" was not a phrase that existed in our vocabulary in the 1970's, but it is rapidly becoming a necessity to actively "manage" machines, not just to passively "monitor" them. Machine "saves" are the purpose for installing a machinery protection system. "Save" usually means a machine has been tripped off-line to prevent serious damage. That is better than a machine wreck. However, the best result is when stresses, which will eventually cause high vibration and the trip, are detected early enough, and the fundamental cause is understood. Then operating parameters can be changed to alleviate the stress and keep the machine running and producing product. That is the objective of machinery management, and the payback is huge. Effective machinery management, and the full benefits provided by today's on-line computerized machinery management systems, are only available if you are

Data Manager® 2000 version 3.0

Enhancements are just one ingredient for your machinery management success



Quick View Configuration

Plot/Configuration: Spectrum Plot

Plot/Configuration: Orbit Plot

Plot/Configuration: Timebase Plot

Plot/Configuration: Shaft Average Centerline Plot

Current Point: BRG #1 X

Figure 1. Version 3.0's "Quick View" option lets you easily select and configure plots.

Data Manager 2000 (DM2000) is Bently Nevada's on-line software for continuous data acquisition and display of machinery condition information from critical machinery. This type of machinery is generally also fitted with our 3300 or 3500 Machinery Protection Systems. As more and more customers obtain the substantial economic benefits that come from use of a machinery management system, the demand for DM2000 grows.

How significant is that demand? We have over 1000 of these on-line systems installed worldwide. With that many systems installed, and dozens more being added each month, Bently Nevada has learned what it takes for customers to derive real value from our machinery management solutions. We've summarized these into three simple lessons we'd like to share with you:

1. ***Data is not enough – information is essential***

   Data Manager® 2000 is inherently a data-gathering system. It does this task very capably. However, it still requires skilled people to review plots and data and to decide what this means regarding each machine's condition. That's why we'd like to remind you once again: our machinery management capabilities don't end with data acquisition. We can also turn this data into *actionable information*™ – intelligent advisories on your machine's condition – and provide recommended corrective actions via our Machine Condition Manager™ 2000 software. Many of our Data Manager 2000 customers have already made the transition from managing data to delivering actionable information to their operators, management personnel, and maintenance personnel. Talk to us about this important competitive advantage that you may be missing.

2. ***Proper configuration is essential***

   While our software is easy to use, much of its power lies in its flexibility and configurability. Fine-tuning the configuration, so that alarm levels and other system features alert you at just the right time, is what we refer to as *optimizing* the configuration. Experience has shown time and time again that those users with optimized systems derive more value from and experience faster payback of their initial investment in the system. Most of those users with optimized systems share a common trait – they've used Bently Nevada's engineering services to provide this optimization.

3. ***Enhancements are essential***

   Software technology evolves rapidly, and so does our understanding of how to improve our products so that they are even easier to use and more powerful. Beginning this year, Bently Nevada software will be updated more frequently. For most of our software platforms, this means a minimum of two updated versions each year. In the remainder of this article, we've highlighted the improvements you'll find in Data Manager 2000 version 3.0.

the condition of the machine. The phase information reduces the possible number of machine faults to a family of possibilities. Two of the main shaft crack symptoms are 1X vibration amplitude change and phase shift. With a knowledge of other symptoms and a detailed history of the machine, you can analyze other plots and process information to reduce the number of possible machine faults. Without the phase information in this trend plot, the possible seriousness of the machine condition could be overlooked.

Rub detection

Absolute and relative phase are useful for detecting rub conditions. Changes in steady state phase, reverse components in orbits or full spectrum plots, and abnormal rate of change of phase during transient conditions can be indicators of a rub condition. Figure 3 shows a steady state polar plot trend during a rub condition. This polar plot shows the continual phase change due to thermal bow modification to the heavy spot, due to a light seal rub. Without phase information, this would only show as a variation in 1X vibration amplitude, and it would be very difficult for the Machinery Specialist to determine the root cause of the generally increasing vibration amplitude. Phase information considerably reduces the list of possible machine malfunctions.

Shaft balancing

Absolute phase angle information is crucial to proper rotor balancing. Phase information is used to compensate for non-dynamic influences (slow roll vector) and to establish influence vectors for individual machines. Once slow roll, unbalance response, and influence vectors are established, it is possible for the Machinery Specialist to balance a rotor in a minimal number of runs.

Shaft mode shape

By comparing the absolute or relative phase between different measurement planes, the rotor's mode shape can be determined. In the simplest case, we compare the phase of a probe signal at the inboard end of the machine to that of a probe signal with the same angular orientation at the outboard end of a machine (Figure 4). If the two signals are in phase, the rotor is operating in the translational (bow) mode. If the signals are out of phase, the rotor is operating in the pivotal mode. Depending on rotor mass, system stiffness, and rotor speed, higher modes of operation can be attained. If more measurement planes exist between the inboard and outboard ends, a better representation of the mode shape can be determined (Figure 5). It's important to realize that you could not determine the rotor's mode shape if you were looking at the amplitude only or just the frequency of the vibration signals. Mode identification probes can also be useful to determine whether a resonance is structural or rotor related. Shaft mode shape information can also be used in determining balancing strategy.

Location of fluid-induced instability

Differential phase is a specific type of relative phase measurement that can be used in determining the source of a fluid-induced instability. The transducers (which, for best results, should be shaft relative) must be in different planes along the rotor and at the same angular orientation. The vibration should be filtered to the frequency of the instability vibration. The phase lag increases (Figure 6) as the axial distance between the instability source and the measurement planes increases.

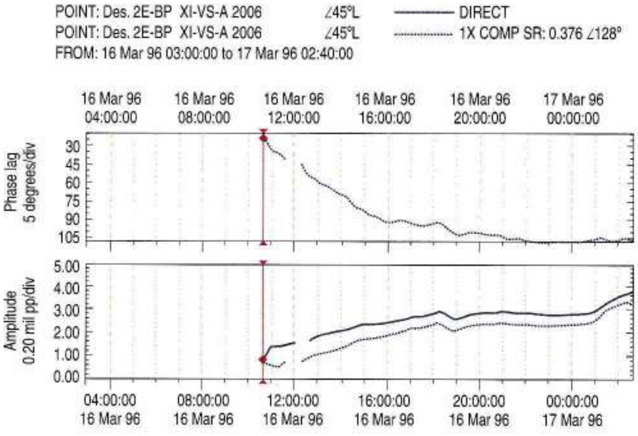


Figure 2. Amplitude and PHase versus Time (APHT) trend plot of 1X vibration due to shaft crack.

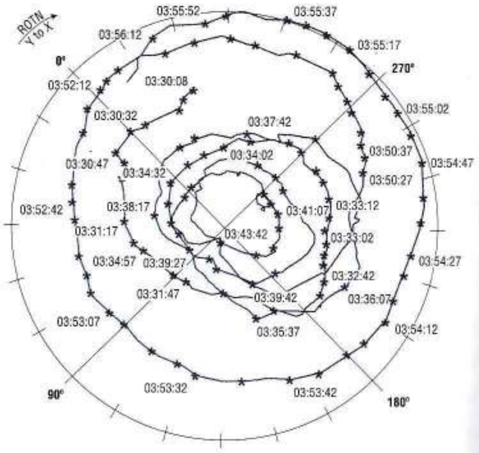


Figure 3. Polar vibration trend plot of steady state vibration due to a seal rub.

Why we must discontinue some products

by Steven W. Riggs

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The Goal - Lasting Value

"The Company takes excellent care of its global customers by providing the right solutions to their business problems based on engineering principles. Through this process, we provide safe, reliable, high quality **products of lasting value** and unequaled service." (From Bently Nevada's Statement of Core Values, emphasis added.)

Bently Nevada's track record in adhering to the above has been, we think you will agree, excellent, and the company continues to drive towards total customer satisfaction. Unfortunately, because we have been so good at supporting our products for long periods of time, some customers, ***and even some of our own people,*** have come to interpret "products of lasting value" as "products which last forever." Regrettably, that is not so. Just because Bently Nevada products which were installed over 20 years ago continue to "work" does not mean they are doing exactly the same job that would be expected of a current design machinery protection and management system. The purpose of this article is to help you to understand some of the many issues surrounding product obsolescence, and to help you to plan the migration from older systems you may have installed to more valuable, state-of-the-art systems.

> *"Much of our core competence is in the design and manufacture of systems that are "fault tolerant," so they don't produce false alarms."*

The evolution of technology

When we design new products, we use the most modern electronic technology and manufacturing processes to increase reliability, performance, and value. Consider the 7200 Series Monitoring System, for example, which was designed in 1974/1975 using components available at that time. Thanks to you, our customers, the 7200 Series was a huge success. When we advised you in 1991 that we would stop manufacturing new systems in 1993, the 7200 Series had been produced for 19 years. We have committed to continue to support the product with available spares and service until 2003. However, is it a good idea for Bently Nevada to continue to encourage the use of a "fleet" of installed systems that represents 25-year-old technology and methodology, and whose average age is over 15 years? We have struggled with this question for some time. In the past, our tendency has been to err on the side of product support rather than product obsolescence. We now think that, in many cases, this is wrong; it may not be in the best interests of most of our customers.

The evolution of knowledge

New products are the embodiment of corporate learning. What we learn about design, component reliability, proper and effective applications, failure modes, diagnostic methodologies, etc., from one generation of products becomes the starting point for the next. Much of our core competence is in the design and manufacture of systems that are "fault tolerant," so they don't produce false alarms. They are also self-checking; that is, they provide assurance that no machine-related alarms are missed because of an undetected fault in the monitor. We sum this up in the following goal: "No false trips, no missed trips!" Current products come much closer to this goal than previous generations of products.

What were considered "best practices" in 1975 are certainly not considered best practices today. Existing installations should be looked at from this perspective: "If I were buying a machinery protection and management system today, would I be happy with the level of performance and capability

Competition is intense and it's global. Differentiation is difficult, so costs have to be managed very aggressively. Mechanical equipment, such as rotating machinery, is one of the single biggest opportunities for reducing costs. Not only can customers reduce maintenance costs when they use machine condition information from one of our systems, but they can better ensure that their machinery is available as well. When market opportunities present themselves to our customers – like the ability to manufacture and sell gasoline or ethylene or electricity during periods of peak demand – this can mean the difference between a profitable year and an unprofitable year. The market recognizes this – just ask yourself how many times you've heard the words "asset management" in the last 12 months – and you know that this topic is of primary concern.

Where next?

Chapman: Integration and "all your machinery" is great – it's what System 1 is all about. However, the real needs are still information-related, not data-related. Our customers need "all the data" to make good decisions, but a system that can reduce the data into information is clearly the new paradigm. Knowledge-based "expert" systems are rapidly moving from "novelty" to "business necessity," and we're leading the charge.

Chitwood: Shortly after initial release of our System 1 software, we'll be adding total and seamless integration of this Decision Support functionality – and, we intend to do it for all machinery – not just our traditional emphasis on turbomachinery.

Sabin: In the near future, we believe just as many plants will be operating with advanced Decision Support tools for their machinery as are currently using advanced control for their process automation. It's really inevitable since the competitive pressures on our customers show no signs of relenting, and the plants with the best access to information – not just data – will win.

The four of you represent combined experience of over 85 years – each of you has seen the Company grow and mature. What is it about this chapter in Bently Nevada's history that you find most exiting – that you are most passionate about?

Riggs: What is most exciting to me now is the changing way in which Bently Nevada is being viewed by our customers. We are being treated not as a seller of parts, but as a partner whose knowledge can make a substantial difference to the success of our customers' businesses. The old model of adversarial, win-lose relationship between buyer and seller is giving way to a model where, unless both parties can win, there is no point in doing business. This is not only satisfying, it is efficient.

Chitwood: We are blessed to have a visionary founder and owner, Don Bently. His passion for the business and our customers is still exciting to me – the new Bently ServoFluid™ Control Bearing he's invented, and the vision he has for how this will change the industry, is just one example. This passion is catching and is a great reason for our success. When you ask what products I am most passionate about, it is impossible to choose – we are developing so many new products right now. Many are not yet announced. From System 1, to the new 3300XL Proximity Transducer System, we have products that really support our mission "Helping our customers protect and manage all their machinery."

Sabin: I'm passionate about all these things – and I love what I do for a living. It is still fun to come to work every day. I think what is most exciting to me is the "atmosphere of expectancy" I feel in the Company. We are all expecting good things to happen because we are growing our product line and service capabilities so aggressively. I don't think I could ask to work with a better team of people who are all committed to the same goals.

Chapman: What I'm most excited about? It would have to be the way our people at all levels are constantly cooperating and pulling together. This is very gratifying to all of us and allows us to focus our time and energy where it belongs – with our customers. After all, without them, we wouldn't have anything meaningful to do.

Note: *Another interview will appear in the 1st quarter 2000 ORBIT. It will feature other members of the Bently Nevada executive management team with responsibilities for Finance, Quality Assurance, Information Systems, and Manufacturing.*

NEW
PRODUCT

3500 TSI Valve Position

Now part of the 3500/45 Position Monitor

by Ingrid Foster
Project Engineer
Bently Nevada Corporation
e-mail: ingrid.foster@bently.com

Turbine Supervisory Instrumentation (TSI) Systems continuously monitor a wide variety of steam turbine generator operating parameters. The TSI system provides monitoring, diagnostic, and predictive maintenance information necessary for protecting and managing turbine generators and other critical machinery. Now, Bently Nevada's advanced 3500 Machinery Protection System has been expanded to include valve position measurement.

Steam turbines vary in design, but, generally, the steam enters the turbine through the main stop/throttle valves and flows to one or more governor valves. The governor valves control the flow of steam into the high-pressure (HP) turbine section. Additionally, after reheat, the steam enters the intermediate pressure (IP) turbine through the reheat stop-intercept valves.

Valve position is varied to maintain or change the load. In a steam turbine, the various possible modes of changing load in megawatts (MW) are:

1. "Single-valve" mode, where a group of governor valves open or close in unison to change the valve flow passage area.
2. "Sequential-valve" mode, where multiple governor valves are sequenced to open or close in a predetermined order at either constant or changing inlet throttle steam conditions.
3. "Sliding pressure" mode, where a group of governor valves are fully open or maintained at a constant partially open position while inlet throttle pressure is changed to vary the flow through the turbine.

In the "single-valve" mode, all the governor valves operate in unison to vary the steam flow to the turbine inlet bowl by changing the amount of valve opening. Large turbines may have a full 360° arc of admission, while smaller units may have a fixed percentage partial arc admission. In the "sequential-valve" mode, the governor valves, as they open and close in sequence, feed steam to the blading through a changing circumferential admission arc. The size of the arc passing steam can be expressed as a percent of full arc admission. In the "sliding pressure" mode, the governor valves remain at a fixed opening and feed steam through a constant arc or percent of admission.

Turbine-generator hold points (for thermal soaking), acceleration-to-rated-speed, synchronization, and loading can be accomplished with flow controlled by either stop valves or the governor valves, using full arc or partial arc admission, or by changing the inlet throttle pressure.

In addition to stop valves and governor valves, there are also reheat stop valves and intercept valves located in the lines between the reheater and the IP turbine. The function of these valves is to protect the turbine against overspeed from stored steam in the boiler reheater section and sometimes to provide additional control function if the valves have been designed accordingly.

Advantages of the 3500 Position Monitor

The 3500 Position Monitor displays the position of a valve as % open or % closed of its full motion. The measurement can be based on linear or rotary motion. Linear motion relates to movement of the valve stem, while rotary motion relates to movement of the cam shaft.

AC LVDTs (Linear Variable

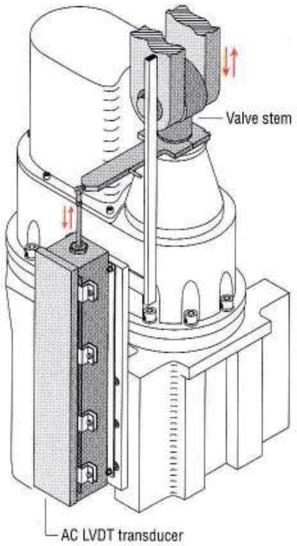

Figure 1. Typical AC LVDT installation on a valve stem.

How our pump lab is increasing our understanding of pump behavior

by Marco Alcalde

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Introduction

Fierce competition is creating intense cost reduction pressures for many of our customers. This is especially true for the oil, gas, and power industries where economic conditions are forcing companies to improve business returns from existing facilities or face the prospect of having to shut them down. Efforts to manage turbomachinery – once the primary focus of machinery protection and management efforts – have given way to intensified programs addressing less critical, rolling element bearing (REB) machinery.

Bently Nevada is recognized as an industry leader in providing solutions for protecting and managing fluid film bearing turbomachinery. However, Bently Nevada has also been successfully managing smaller, rolling element bearing machinery for many years. In fact, our Machinery Diagnostics and Machinery Management Services organizations regularly help our customers manage this type of machinery. In addition, we have an in-house pump lab to further our understanding of pump behavior. In subsequent ORBIT magazines, we will chronicle the results of our research and include case histories gathered from our Services Engineers.

Pump lab research objectives

As a result of industry's changing needs, Bently Nevada Corporation launched a project in April 1998 to build a pump laboratory and begin in-house research into the behavior of pumps, pumping systems, and low-cost condition monitoring solutions. The primary objective of this research is to determine the most effective measurements for managing rolling element bearing machinery, especially pumps. Our research will be based on sound engineering principles rather than rules-of-thumb, or on the presumed ease of making a reliable casing seismic vibration measurement.

A second objective is to provide research support for our Machinery Management Services Engineers. On a daily basis, these engineers encounter and solve pump and other rolling element bearing machinery problems. This includes work with OEMs and end-users. Unfortunately, the plant environment provides limited flexibility to investigate and understand some types of problems. However, a combined effort enables us to validate in the field what we are discovering in the laboratory. The pump lab is helping us understand the fundamental engineering principles and develop cost-effective machinery management solutions.

Apparatus

Figure 1 shows a diagram of the first pump installed, instrumented, and tested in the pump laboratory. The pump, a 4x3x7.5 single volute, overhung design with a 5-vane enclosed impeller, is driven by a 7.5 hp motor. The best efficiency point (BEP) is 14.5 m (47.5 ft) @ 21 L/s (330 gpm) at 1770 rpm. The impeller and shaft are supported by two rolling element bearings and are coupled to the motor with a rather soft coupling. The motor can be driven directly from the power line at 480 V and 60 Hz or from a 480 V variable frequency drive.

The pump loop is supplied with water from a 6000 liter (1600 gallon) tank. The water level of the tank is typically 2 metres (6.5 feet) above the pump inlet. The water is supplied through a 152 mm (6 in) manifold to each of three pump pedestals. Two pedestals can support a 40 hp pump installation, and the third pedestal can support a 20 hp pump. The loop can support up to a 50 L/s (800 gpm) pumping rate. The pumps can be connected either in parallel, series, or a series-parallel combination.

Electronic overspeed detection systems

by Jeff Rudd

Project Applications Engineer
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Mechanical versus Electronic Overspeed Systems

Users understand all too clearly the catastrophic results of an overspeed event. Unfortunately, mechanical overspeed protection systems suffer from numerous shortcomings. Even for those mechanical overspeed protection systems that are in perfect working order, two unavoidable aspects of testing these systems render them undesirable: the machine must be removed from its production capacity *and* physically oversped to test the system. In other words, to test your mechanical overspeed protection system, you must stop producing product and put the machine into an unsafe (overspeed) condition. How serious is this? Consider the following: the insurance industry estimates that fully 50% of catastrophic overspeed events occur when the mechanical overspeed protection system is being tested. With the typical test lasting from a few hours to a full day, the lost production is substantial.

Industry recognizes these issues and has recently begun emphasizing the superiority of Electronic Overspeed Detection Systems (EODS). For example, when a user elects to use American Petroleum Institute (API) Standard 612, it mandates that the overspeed system must be electronic, rather than mechanical, and that it use 2-out-of-3 voting. This approach addresses both the safety considerations and the economic considerations. The 2-out-of-3 voting arrangement provides the optimum balance between the probability of a missed trip and the probability of a false trip. The 2-out-of-3 voting also permits you to test the system by electronically simulating an overspeed event in each channel while still leaving the other two channels on-line to protect the machine. Globally-respected standards, such as API 612, are removing the option for mechanical overspeed systems. Instead they are requiring that machines conforming to this standard use only 2-out-of-3 voting electronic systems. The message is clear: an EODS is the new minimum standard for good engineering practices.

3500 – the ideal platform for EODS

For many years, Bently Nevada has been at the forefront of Electronic Overspeed Detection Systems. We're now producing our third generation of such systems. We started with our 7200 Series product (offered only in Europe), then developed our 3300 Series product, and now manufacture our current offering, the 3500/53. With installations worldwide, we've learned what it takes to make a system that is reliable, that has integrity comparable to other fault-tolerant safety instrumented systems, and that has the conveniences and features users need. In addition, our 3500/53 EODS modules can reside in their own stand-alone rack (as required in API 612) or can reside with other 3500 monitor modules, allowing you maximum flexibility in system design, depending on your philosophy. By using the 3500 System's Communication Gateway module(s), your EODS can be easily integrated with process control systems to give operators instant access to all EODS statuses and values.

Eddy current transducers increase reliability

In all overspeed protection system applications, sound engineering principles must be used when you select speed-sensing transducers. After all, the system is only as good as its input signals. Eddy current proximity probes provide superior performance compared to magnetic pickups. Several of the most significant advantages of eddy current transducers compared to magnetic pickups include:

- Uniform, speed-independent response to zero speed.
- dc gap voltage readings for setting and fault checking.

  Gap voltage readings provide information on runout and physical gap, and also enhance transducer and

Magnetic bearings ... do their problems outweigh their benefits?

by Donald E. Bently

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The active magnetic bearing is not a panacea – not a solution to all existing problems. This technology has significant problems and limitations, tempering its claims and forcing trade-offs. While actively controlled bearings are an exciting prospect, creating revolutionary opportunities for how rotating machinery is designed and operated, the use of magnetic force to achieve this control is a technology with a troubled history. This article looks closely at active magnetic bearings and summarizes their limitations.

Active magnetic bearings – technology with a troubled history

Active magnetic bearings offer some degree of active bearing control, but suffer from three significant, fundamental weaknesses:

1. Usually inadequate heat removal from the bearing.
2. Poor rotor support mechanism when active control fails.
3. Lack of adequate force compensation and inherently low dynamic stiffness.

Magnetic bearings have been in use since the early 1980s, and these problems have not been resolved. Machines that have been retrofitted with new rotors and magnetic bearings are experiencing the most difficulties. Even some newly-designed machines incorporating magnetic bearings have not been trouble-free. When users have tried to reduce maintenance costs by installing magnetic bearings, some have actually experienced more unplanned shutdowns and increased operating costs. Several manufacturers of active magnetic bearings and their related controls have gone out of the business. These are all signs of a technology that is not robust.

Weakness #1 – Excessive heat

Heat is generated in magnetic bearings by two primary mechanisms: the eddy current losses in the stator cores and machine rotor and the resistance losses in the coils. This heat can cause a number of problems.

- **Thermal bowing of the rotor may occur if the heating in the rotor surface is uneven.**
  Eddy currents are generated in the surface of the stator core and the rotor by the alternating magnetic field and flow in closed paths. Since the paths are resistive, the currents generate heat in the core or rotor. In an attempt to minimize eddy current losses, modified or new rotors are used that have a continuous spiral of a thin steel lamination in the bearing areas. This generates the additional problem of a unique, matched rotor/bearing system.
- **The heat will eventually destroy the active magnetic bearing, by breaking down the coil insulation and causing electrical shorts.**
  This second heating source comes from the wire resistance in the wound coils. Since normal copper wire has a resistivity that increases with temperature, heating can spiral out of control if there is no way to remove the unwanted heat.
- **Rubs can result when control of unbalance response is eliminated to reduce the heat generated.**
  When large loads are encountered during operation, the thermal load becomes a significant limitation on real-time control. Most magnetic bearing manufacturers eliminate real-time control of the synchronous (1X) and nX components to reduce the heat problem. This can create significant problems for machines that have tight clearances: when the balance condition changes, the rotor, which is allowed to rotate around its mass centerline, will soon rub

Root locus analysis –
An excellent tool for rotating machine design and analysis

by John W. Grant
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The potential for unstable operation is inherent in all feedback control systems. Consequently, it is desirable to analyze their stability characteristics and their damping characteristics so that both the absolute stability and the relative stability (peak overshoot, settling time, etc.) of the system can be determined. Classical control theory uses a method commonly known as root locus analysis, developed by W. R. Evans [1] in 1948, to accomplish this.

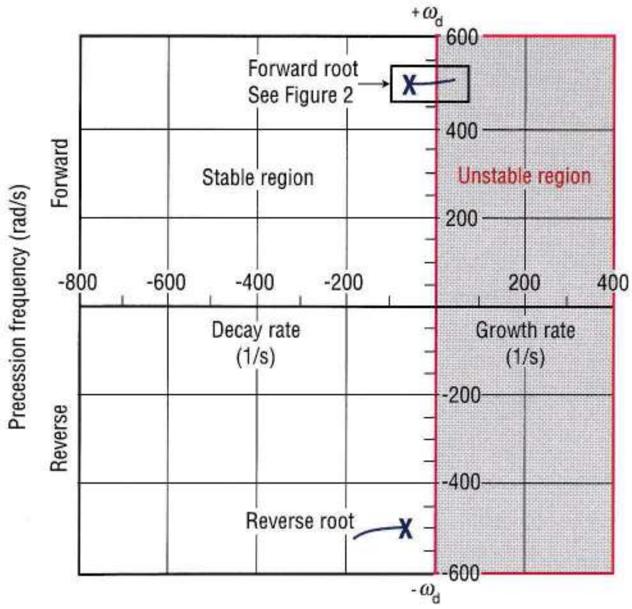
All rotating machines can be modeled as closed loop control systems, where the machine responds characteristically to forces and moments. This allows them to be studied using control theory techniques. Historically, graphical tools, such as Campbell diagrams and logarithmic decrement plots, were used to determine a system's natural frequencies and damping factors. These methods can be cumbersome and cannot provide a method of analysis. However, design and analysis can be obtained from a graphical representation of the root locus.

To understand some of the features of root locus analysis, consider a simple model for a rotor supported in a fluid-film bearing. The equation for the characteristic response of a rotor/bearing/seal system is:

$$Ms^2+Ds+K-jD\lambda\Omega = 0$$

Where M, D, and K are the lumped generalized first lateral mode inertia (lb·sec^2/in), damping (lb·sec/in), and stiffness (lb/in), which encompass the bearing's hydrodynamic and hydrostatic (externally pressurized) fluid-film direct stiffness, and the shaft radial stiffness, λ, is the fluid circumferential average velocity ratio (dimensionless), and Ω is the rotor rotative speed (rad/s).

The roots of the characteristic equation are determined by treating it as a quadratic equation. The rotor speed is incremented from zero, and the roots calculated and plotted. Any parameter can be iterated in this manner to determine the sensitivity of the system to variations of that parameter. Since this is a second order system, two complex roots will exist (Figure 1), that move in opposite directions as rotative speed increases. In the plot, the positive portion of the vertical axis is the forward precession (in the same direction as the rotor rotation) rate of the rotor response, and the negative portion is the reverse precession (opposite rotor rotation direction) rate. The horizontal axis is the rate at which the amplitude of the shaft motion decreases or increases. The



In this graph:

1) The variable parameter is rotor rotative speed, Ω
2) There are two root loci: one for forward precession ($+\omega_d$), one for reverse precession ($-\omega_d$).
3) The forward root becomes unstable at Ω =1050 rad/s.
4) The reverse root poses no threat to stability because it moves toward greater stability.
5) "X" indicates Ω=0

Figure 1. Root locus plot for a simple rotor system.

ued, we realized that the turbine would not have suffered any significant damage. It also would not have been necessary to open any turbine section. However, identifying and correcting the attemperation valve problem certainly avoided additional trips. Without the data from the DM2000 System, we wouldn't have been able to identify the problem so quickly and accurately. **Thus, the real story here is the savings the DM2000 System generated.** The application of diagnostic and predictive maintenance techniques at our plants is instrumental in avoiding unplanned shutdowns, which is crucial to meeting our customers' power requirement and optimizing our profitability in the wholesale electric market.

An unplanned unit shutdown can significantly affect our activities in the wholesale power market, including reversing our position from a net seller to a net buyer. Last summer, the Midwest experienced several hot, humid months, including a late June heat wave, which precipitated unprecedented price levels in the wholesale electric market in the Midwest. Prices in the Day-Ahead market, which involves daily prescheduled energy blocks for the sixteen on-peak hours of the following day, were frequently in the $30-$50 per MWh range, with a number of peak days exceeding $100 and even $1000 per MWh. Similarly, prices in the hourly marker, which involves the trading of hourly energy blocks, were often in the $50-$100 MWh range.

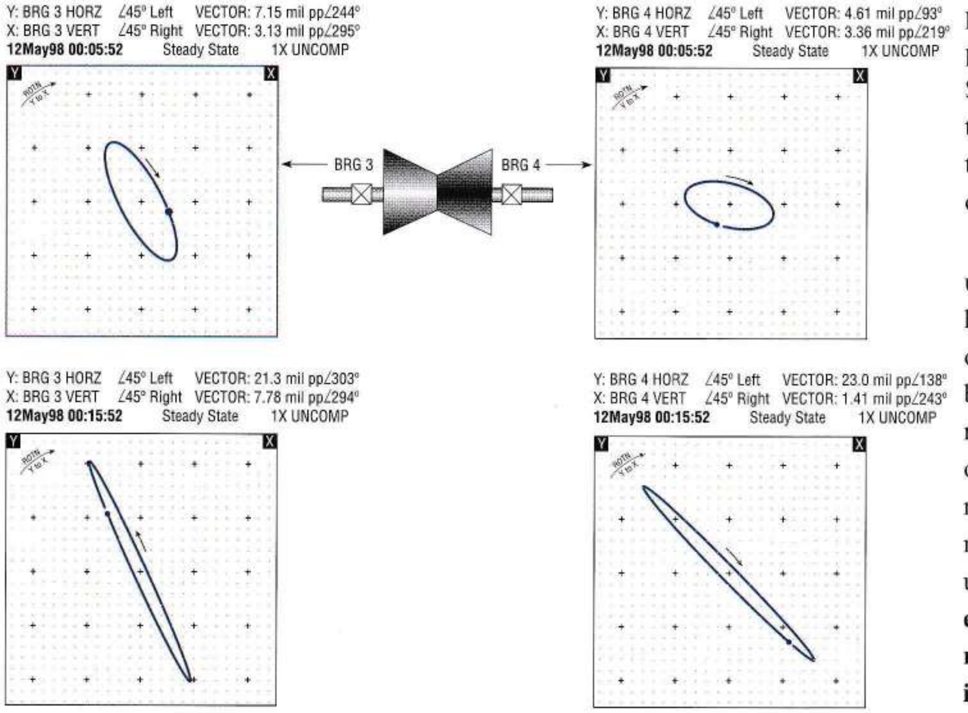


Figure 3a. 1X shaft orbits at bearings 3 and 4. Top plots show response shortly after startup. Bottom plots show effects of thermally-induced rub.

With these market conditions, the unexpected loss of a large unit can have substantial financial impact in only one afternoon. As an example, based upon the available spinning reserve at the time of the trip, the loss of a 1300 MW unit may lead to the need to purchase 700 MW of replacement power in the hourly market for up to 4 peak hours. **Assuming an energy cost of $100/MWh, the resulting replacement energy cost is 700 MW x $100/MWh x 4 hours = $280,000 for a single trip, and potentially a great deal more!**

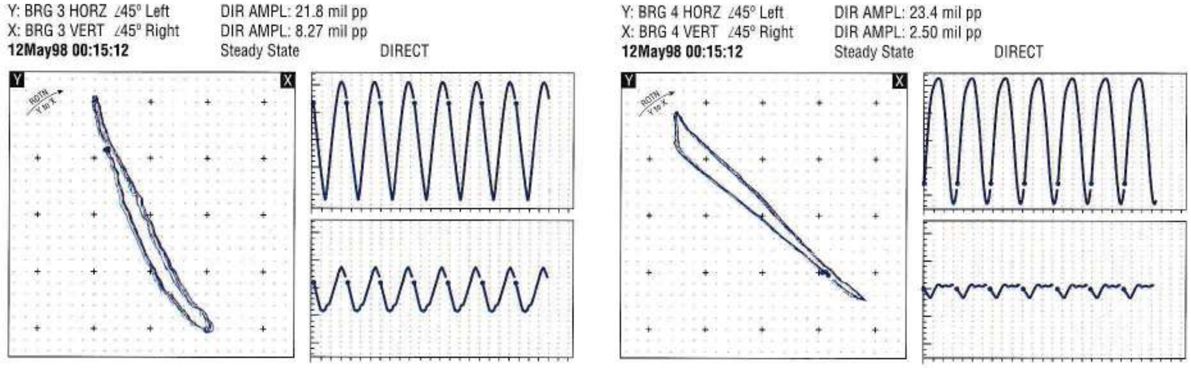


Figure 3b. Direct orbit and timebase plots of response due to thermally-induced rub at bearings 3 and 4. Notice truncated response of waveform in positive X probe direction at bearing 4 indicating duration of contact. Corresponding flat area of orbit shows orientation of rub location.

ORBIT
A Technical Publication of Bently Nevada Corporation

Second/Third Quarters 1999

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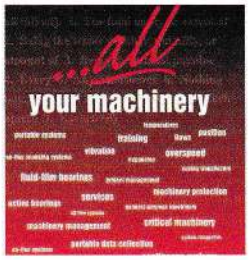
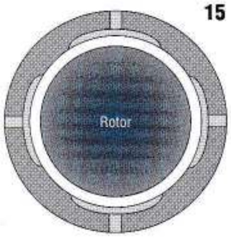


Cover: *all* your machinery. See editor's note on the preceding page.



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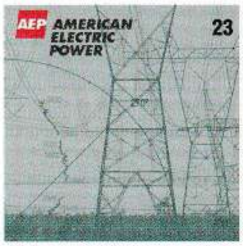

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Why phase information is important for diagnosing machinery problems

by Clair Forland
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Accurate diagnosis of machinery problems requires a complete set of machine vibration information. That information comes from the three primary parts of the data that we can obtain from a vibration signal: direct amplitude, frequency, and, when there are two signals, phase. Relative phase is the timing relationship between two vibration signals, while absolute phase compares a vibration signal to a once-per-turn reference pulse. The Keyphasor® signal is a once-per-turn voltage pulse provided by a transducer (normally a proximity probe). The Keyphasor signal is used by monitoring, diagnostic, and management systems to generate filtered vibration amplitude, phase lag, speed, and a variety of other information. Keyphasor-generated information can help the Operator or Machinery Specialist identify developing machine problems or distinguish serious problems from less serious ones. The Keyphasor signal is used to generate more than one third of the information regarding the condition of the machine. Phase (relative and absolute) is a critical part of this information. Without phase information, overall machine condition and machine faults would often be very difficult, if not impossible, to diagnose.

Why is phase important?

Phase information can be used to detect subtle changes to the machinery that may otherwise go unnoticed. Listed below are a few of the many phase angle applications:

- Trending for Acceptance Regions
- Shaft crack detection
- Rub detection
- Shaft balancing
- Shaft/structural resonance detection
- Shaft mode shape
- Location of a fluid-induced instability

Trending amplitude and phase information can provide early shaft crack detection and alert the Operators to other possible machine problems. Rub conditions can be detected with the use of phase presented in steady state polar plots. Machinery Specialists use phase extensively in their analysis to confirm suspected machine problems.

Trending phase information

The Acceptance Region trend format is a polar or rectangular coordinate plot (Figure 1) produced by sampling vibration vector components as a function of time. Acceptance Region describes a range of vector movements considered acceptable for normal machine operation. Such trends should be maintained for 1X, 2X, and slow roll vectors. Any movement of these vectors outside of the acceptance boundaries should be viewed with suspicion. Correlation of the 1X and 2X vectors with load, field current steam conditions and other process parameters is used to determine whether vector shifts are caused by a shaft crack or by other factors. Changes in the slow roll vector can be caused by shaft crack and rotor bow.

Shaft crack detection

The Amplitude and PHase versus Time plot (APHT plot) (Figure 2) shows that 1X vibration amplitude is continually increasing. Note that the increase in vibration amplitude level is only half of the picture. The continual change in phase shown in the plot reveals critical information regarding

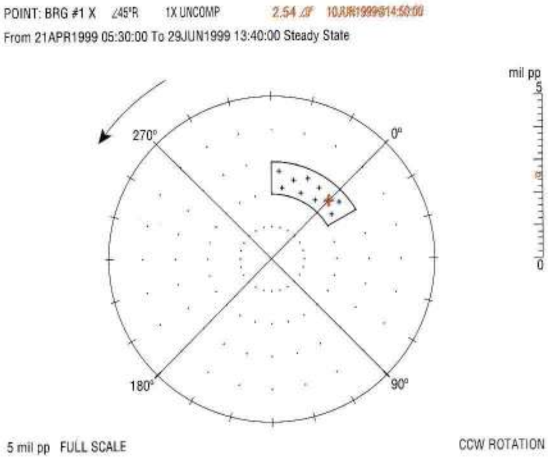

Figure 1. Data Manager® Acceptance Region plot of 1X or 2X vibration vectors.

Transducers

To provide the required visibility into the pump's performance and condition, the pump was fitted with 17 transducers. The transducer locations are indicated in Figure 1 and Table 1.

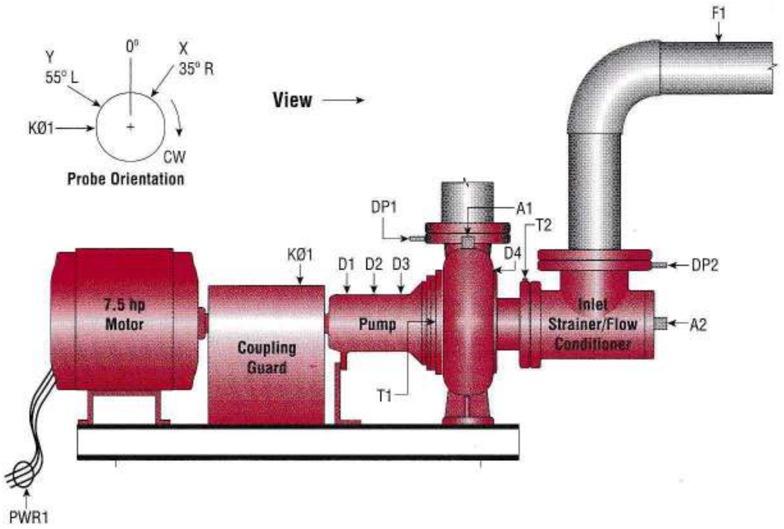

Figure 1. Illustration of transducer locations.

Dwg.Ref.	Transducer	Qty	Location	Orientation
D1	Eddy current REBAM	2	Drive end (DE) REB	X 35° Right Y 55° Left
D2	Eddy current displacement	2	Shaft observing between NDE and DE REBs	X 35° Right Y 55° Left
D3	Eddy current REBAM®	2	Non-drive end (NDE) rolling element bearing (REB)	X 35° Right Y 55° Left
D4	Eddy current displacement	2	Wear ring area	X 35° Right Y 55° Left
KØ1	Keyphasor®	1	Pump shaft	90° left
T1	Thermocouple	1	Inlet water	N/A
T2	Thermocouple	1	Nonrotating ceramic seal ring	N/A
F1	Flow	1	10 pipe diameters before pump inlet elbow	In line
DP1	Dynamic Pressure	1	Outlet	N/A
DP2	Dynamic Pressure	1	Inlet	N/A
A1	Acceleration	1	Pump housing	0°
A2	Acceleration	1	Inlet cap	Axial
PWR1	Dynamic Power	1	Motor power lines	N/A
	Microphone	1	Various locations	N/A

Table 1. Table of transducer locations.

Pump performance testing

When the pump loop became operational in September 1998, the first test was to verify the manufacturer's head curve data. This ensured that the loop design did not cause the pump to operate outside its design parameters. This test also reproduced the NPSHr (Net Positive Suction Head required) curve for the pump. These test results agree with the stated manufacturer's data reasonably well (Figure 3). During this testing, baseline data was gathered from all of the pump and process transducers.

Pump cavitation testing

The next test was to reduce the NPSHa (Net Positive Suction Head available) and observe the changes in the baseline data under conditions of cavitation and reduced flow. The conditions for the onset of cavitation, as defined by the Hydraulic Institute Standards, are a 3% drop in head (NPSHa) while operating at a constant flow, no inlet or discharge throttling. These conditions are established by creating a closed pumping system, operating at a fixed flow rate, and then reducing the inlet pressure on the closed system by drawing a vacuum on the loop.

The first observation was that there was no change in the pump's audible frequency emissions when cavitation occurred. We expected to hear sounds "like marbles are inside the pump." However, as the NPSHa was reduced, there was no audible indication. According to the Pump Handbook [1], "A steady crackling noise in and around the pump suction indicates cavitation. A random crackling noise with high-intensity knocks indicates suction recirculation rather than cavitation from inadequate NPSH." The Pump

Using Data Manager® 2000 to compete in the wholesale power market

by Ken Davis

Sr. Engineer Operations Services
American Electric Power

and Jim Cable

Sr. Turbine Engineer
American Electric Power

American Electric Power (AEP) is a global energy company and one of the largest investor-owned utilities in the United States. Our facility at St. Albans, West Virginia, is a coal-fired generating plant, which produces 2900 MW of power. We use a Bently Nevada 3300 Turbine Supervisory Instrumentation System and proximity probes to monitor the three turbines in our plant. We also recently installed a Data Manager® 2000 System on our 1300 MW, cross-compound, Asea Brown Boveri (ABB) turbine generator as part of a system demonstration.

The locations of the eight bearings on each turbine-generator shaft, HP and Reheat, are the same, but are quite different from the standard bearing arrangement used by many American turbine manufacturers (Figure 1). The HP turbine rotor has the standard two bearings, but on the LP A rotor there are no bearings within its coupling span. On the LP B rotor, there is only one bearing on the governor end. There are bearings on each end of the generator and the exciter.

The Data Manager 2000 (DM2000) System automatically collects and processes vibration and process data during both steady state and transient (startup and coastdown) machine operation. Under steady state conditions, the DM2000 System samples all configured points once every four seconds and retains the minimum, maximum, and average value for each point over a ten-minute interval. The DM2000 can be configured to automatically capture data by intervals of delta rpm, delta time, or both, during startup and shutdown.

Vibration triggers overspeed bolt, trips turbine

In April 1998, we completed a long outage, during which the two LP turbines on the HP shaftline were inspected and refurbished. After the outage, we operated the turbines successfully until the unit was forced from service on April 26, due to high vibration on the HP turbine shaftline. Initially, vibration levels only increased on the T-3 and T-4 bearings, but vibration amplitudes on the other bearings, including the T-1 bearing, soon increased as well. At the time, unit operators suspected that the vibration may have been caused by turbine backpressure, but attempts to lower the backpressure to reduce the vibration were not successful. Vibration levels continued to increase until the HP turbine 110% overspeed bolt operated and tripped the turbine and the unit. As we experienced previously, the overspeed bolt operated, due to the high vibration at the T-1 bearing and front end of the HP rotor. Following the trip, a root cause analysis was initiated but couldn't be accomplished, as the turbine vibration data acquisition system was not in service at the time of the trip. Therefore, further analysis of the vibration

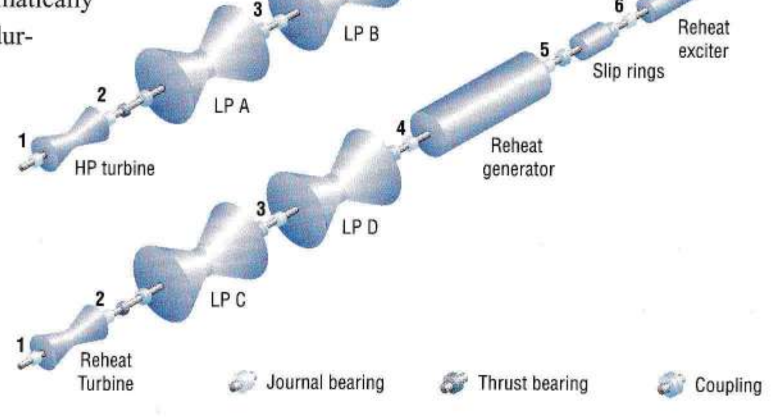

Figure 1. Block diagram of ABB 1300 MW, cross-compound turbine generator.

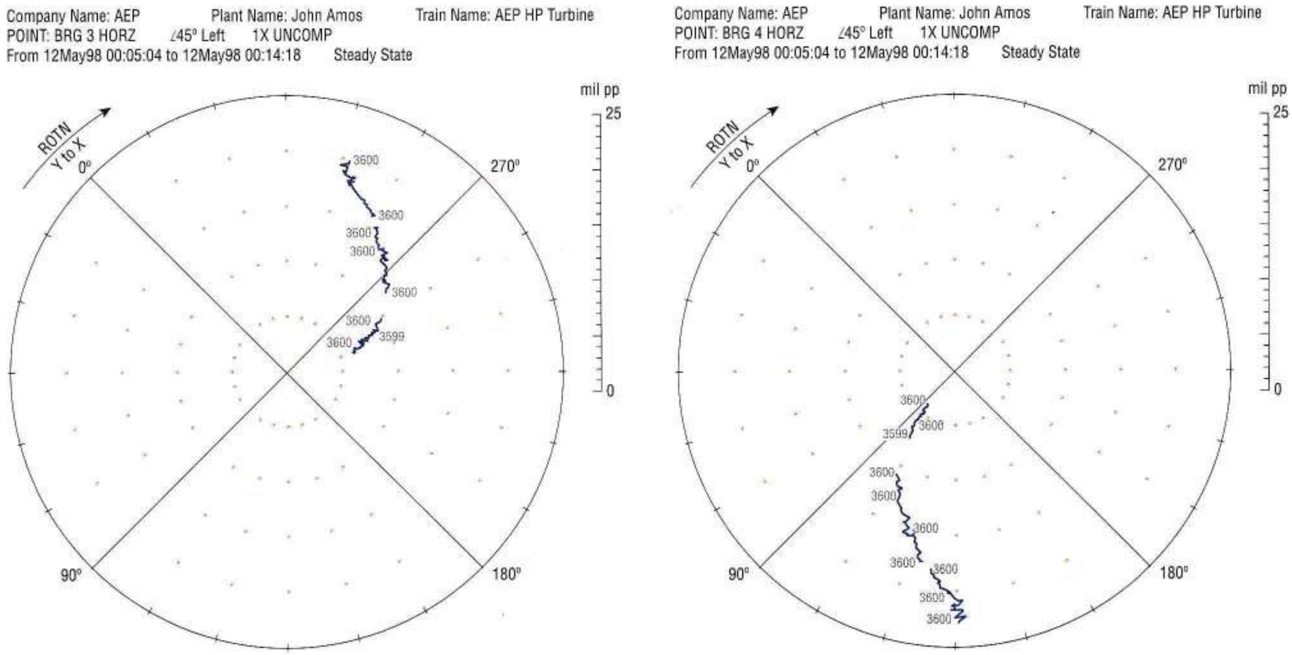

Figure 2. Steady state vibration response at bearings 3 and 4 due to thermally-induced rub.

characteristics was not possible. The unit's Sequence of Events Report (SER) printout did not indicate any pre-trip events that may have contributed to the vibration excursion. Also, no abnormal data, which could be related to the trip, had been reported in the control room.

Second machine trip

The unit was returned to service and operated successfully until May 12, when System Dispatch asked that the unit load be reduced to minimum. Similar to the events of the previous trip, the vibration levels first increased on the T-3 and T-4 bearings. The other bearings quickly followed, including the T-1 bearing, until the overspeed bolt again tripped the turbine. Once again, a root cause analysis was initiated. The premise was that unit load changes, with their associated thermal influences, might be creating a rotating-to-stationary-component rub. In particular, since the LP turbines had recently been overhauled, we suspected that the tight seal clearances were the most likely source of the rub. Therefore, we began to evaluate the vibration data for evidence of a rub. Since the DM2000 captured vibration amplitude, phase angle, and frequency data before and after the unit trip, we had access to information which could help identify a thermal rub. Characteristically, during a thermal rub, the phase angle and the vibration amplitude both change gradually over time, and the vibration frequency is predominately 1X (synchronous). A quick review of the polar plots from the Data Manager 2000 System (Figure 2) showed that the vibration amplitude and phase lag increased as the rub-induced bow changed the balance condition of the LP rotor. Therefore, we concluded that an LP turbine rub had occurred.

In addition, the timebase and orbit plots for bearings 3 and 4 (Figure 3) clearly showed the restraint and noncircular centerline motion of the shaft. This is very consistent with a rub malfunction. The orbit at bearing 3 was also "reverse" precession (against the direction of rotation) orbit. This is caused by tangential forces acting on the rotor, due to friction from the rub event.

Thermal analysis

After diagnosing the LP turbine rub, we began to look for possible thermal influences that may have initiated the rub. For an LP turbine rub, the turbine gland seal system is often found to be the culprit. Upon inspection, it was found that the steam seal system's attemperation (desuperheater) valve was malfunctioning, due to a problem with an air solenoid valve that supplies its controlling signal. The valve problem, in conjunction with the tight LP seal clearances, resulted in a gland seal rub with the LP rotor. After the valve was repaired and temperature control was returned to normal, no further vibration excursions have occurred.

Conclusions

After reviewing the probable results if the rub had contin-

Vilfredo Pareto
(1848 - 1923)

"In any series of elements to be controlled, a selected small fraction, in terms of numbers of elements, always accounts for a large fraction in terms of effect."

Vilfredo Pareto, noted economist and sociologist, is best known for his law of income distribution, which is often called Pareto's Law or the 80/20 Rule. This law is a mathematical formulation in which he attempts to prove that the distribution of incomes and wealth in society is not random, but exhibits a consistent pattern. This relationship follows a regular logarithmic pattern and can be charted in a similar shape, regardless of the time period or country studied.

The formula is:

$$\text{Log}\ N = \log A + m \log x$$

where N is the number of income earners who receive incomes higher than x, and A and m are constants. In simplified terms, 80% of the wealth is owned by 20% of the population.

Relating Pareto's Law to machinery protection

The 80/20 Rule has also been found to apply in many other fields, including machinery protection and management. For example, in a large percentage of plants, most of the machinery problems and associated economic costs are caused by a relatively small population of machines. Although this split is not always an exact 80/20 division, Pareto's general principle still applies. Most machinery problems in a plant are caused by a small percentage of machines.

Today, "Pareto analysis" is a commonly-used method of separating the major causes (the "vital few") of a problem, from the minor ones (the "trivial many"). It helps prioritize and focus resources where they are most needed by showing where initial effort should be placed to produce the most gain. It also helps measure the impact of an improvement by comparing before and after conditions.

Pareto diagrams or charts effectively display the relative importance of causes, problems, or other conditions. In the machinery management and protection example, analysis of which machines are causing the bulk of the problems can be used to justify new management and protection efforts and to demonstrate the financial impact consequently realized from such efforts.

Pareto studied Civil Engineering at the University or Turin, Italy. The first two years at the university were devoted to mathematics, which deeply influenced his future intellectual outlook. From 1870 to 1893, he worked as an engineer, studied philosophy and politics, and also wrote many articles. He was one of the first people to analyze economic problems using mathematics. Vifredo Pareto died in 1923. That his ideas continue to be discussed and debated suggests their impact and timelessness.

References

1. *The Forbes Book of Business Quotations*, edited by Ted Goodman, Black Dog & Leventhal Publishers, Inc., 1997.
2. Fr. James Thornton, *Vilfredo Pareto: A Concise Overview of His Life, Works, and Philosophy,* http://www.panix.com/~jk/pareto.html.
3. *Vilfredo Pareto Guide*, Department of Economics, University of Melbourne, http://www.ecom.unimelb.edu.au/ecowww/rdixon/pareto.html.
4. Richard Koch, *The 80/20 Principle: The Secret of Achieving More with Less*, 1998.

There's more to balancing than adding weights to your machine

by Don Southwick

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To learn how to balance a 500 MW steam turbine generator set, an overhung pump, or a gearbox, etc., you need to practice balancing a 500 MW steam turbine generator set, an overhung pump, or a gearbox. **For this reason, the on-site balancing courses provided by Bently Nevada are specifically tailored to your machinery and your needs.**

Before you insert balance weights into ***any*** machine, you need to determine the following:

Is unbalance the root cause of the problem?

Balancing is rarely a valid solution to anything except an unbalance problem. If any unusual responses result during a balancing job, special attention must be given to the possibility of a shaft crack. Do you know the symptoms? Do you know the difference between "usual" and "unusual" responses?

What are the balance characteristics of your machine?

- Location of rotor mass.
- Mode shapes.
- Location and number of balance planes.
- Influence vectors at different machine speeds.
- Influence vectors at different machine loads.
- Thermal or environmental effects.
- Anisotropic stiffness effects on weight placement.

Will balancing cause other machinery problems to appear?

It can be very disconcerting to find that your well-balanced machine now has a fluid-induced instability (whirl or whip) or rub problem. However, depending on the machine, these results shouldn't be entirely unexpected.

What is the balance history of the machine?

Knowing what size weights were used, where they were placed, what influence vectors were computed, and what problems resulted, is essential to an efficient, successful balancing operation.

The Bently Nevada on-site balancing course teaches you the techniques needed for that successful balance job. Learn why influence vectors and calibration weights are so important for effective single plane balancing of fans and other low-speed machinery.

Understand why the information contained in polar plots is essential for multiplane balancing of machines operating above their second balance resonances. Learn the value of virtual probe rotation when balancing machines with anisotropic support stiffness. Classroom instruction and hands-on workshops provide a good foundation in balancing fundamentals before you attempt to balance your machine. Hands-on training ***on your machines*** helps reinforce this training.

> *"To learn how to balance a 500 MW steam turbine generator – you need to practice balancing a 500 MW steam turbine generator..."*

Contact your nearest Bently Nevada sales or service professional to arrange for a balancing course at your site.

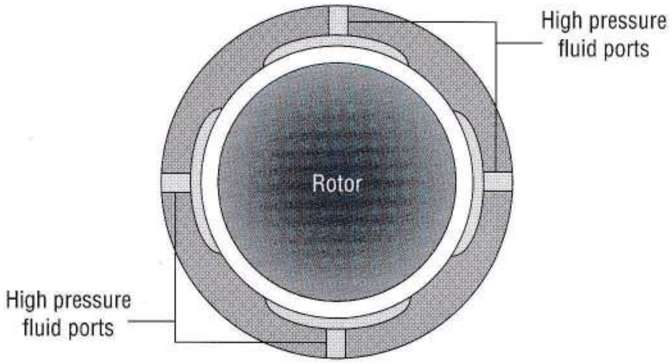

Figure 2. Typical control bearing cross section.

bearing, and they measure both the static and dynamic position of the rotor relative to the stator. The control system uses linear-type PID (proportional-integral-derivative) controllers.

Bearing evolution

The first recorded wooden bearings were on wagons preserved from the third millennium B.C. About 2000 B.C. in Jericho, the first use of lubricant in bearings was recorded. They were the precursor to the modern cylindrical fluid-film bearing which enabled the development of high-load, high-speed machinery. Cylindrical bearings started another evolutionary process that deals with their susceptibility to fluid-induced instability. Dams, pockets, modified geometry, and tilting pads followed, in attempts to add radial forces and interrupt the continuous fluid path to increase the stability of the bearing. Although the stability of the bearing increases, trade-offs involve uniqueness, decreased load-carrying capability, increased size, and increased cost.

Benefits of fluid-film bearings include:

1. Long life.
2. High load carrying capacity.
3. Ability to handle high rotor speed.
4. Intrinsic damping.
5. Ability of fluid to remove unwanted heat.

Problems include:

1. Susceptibility to fluid-induced instabilities.
2. Low rotor eccentricity ratio that reduces direct stiffness, reducing the stability margin.
3. Difficult on-line control of the rotor dynamic properties and related malfunctions.

The first recorded use of rolling element bearings in rotary motion is in A.D. 50 in two Roman pleasure boats recovered from Lake Nemi, Italy [1]. A typical rolling element bearing supports the rotor load using the element-to-race or element-to-fluid-film contact. Rolling element bearings enabled the development of smaller, low-speed machines, especially ones which can operate below mechanical rotor resonances.

Benefits of rolling element bearings include:

1. High direct stiffness, until the bearing wears, reducing contact.
2. Self-contained lubrication system or lubricant sealed inside.
3. Lower cost than fluid-film bearings.

Problems include:

1. Finite life due to high contact forces and metallurgy limitations.
2. Poor damping characteristics.
3. Limited load-carrying capacity.

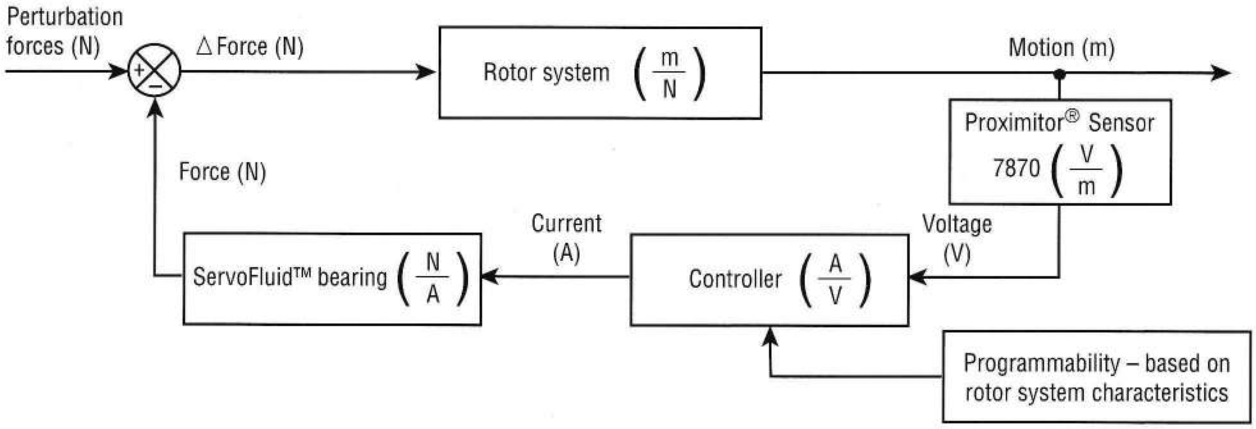
Perturbation forces (N)
+
−
△Force (N)
Rotor system $\left(\frac{m}{N}\right)$
Motion (m)
Proximitor® Sensor 7870 $\left(\frac{V}{m}\right)$
Force (N)
Current (A)
Voltage (V)
ServoFluid™ bearing $\left(\frac{N}{A}\right)$
Controller $\left(\frac{A}{V}\right)$
Programmability – based on rotor system characteristics

Figure 3. ServoFluid™ Control Bearing system block diagram.

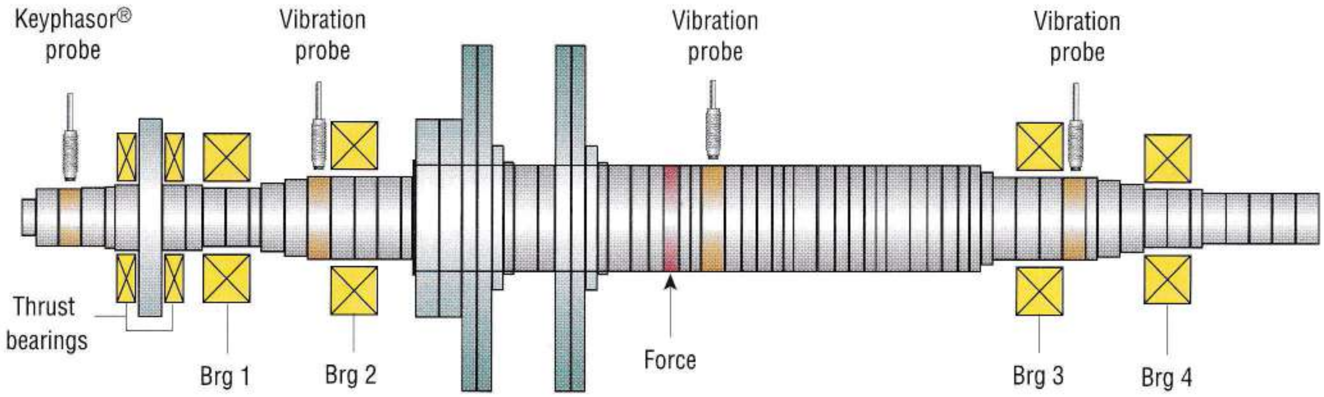

Figure 5. Finite element model of compressor rotor showing the location of bearings, vibration transducers, and force input.

Problems include the limitation of bandwidth by the lowest resonance frequency of the control loop. Real-time control is currently limited to approximately 12,000 cpm.

Benefits for OEMs

Machinery OEMs will find major benefits from this new bearing technology. It provides the designer with the flexibility to optimize the design of the machine, to meet the requirements of special applications, and to increase efficiency while keeping costs down.

Dynamics: Because the length-to-diameter (L/D) ratio of the bearing is small, pairs of bearings (Figure 4) can be used to more effectively control rotor modes (Figure 5) by creating moments, effectively stiffening the shaft. This can more than double the frequency of the lower resonances. Pairs of bearings provide moment (cantilevered) support, while traditional bearings provide only vertical support.

Both of these changes allow designers to use shorter rotors with smaller diameters. Shorter rotors allow machines to be designed with rotor resonances outside the

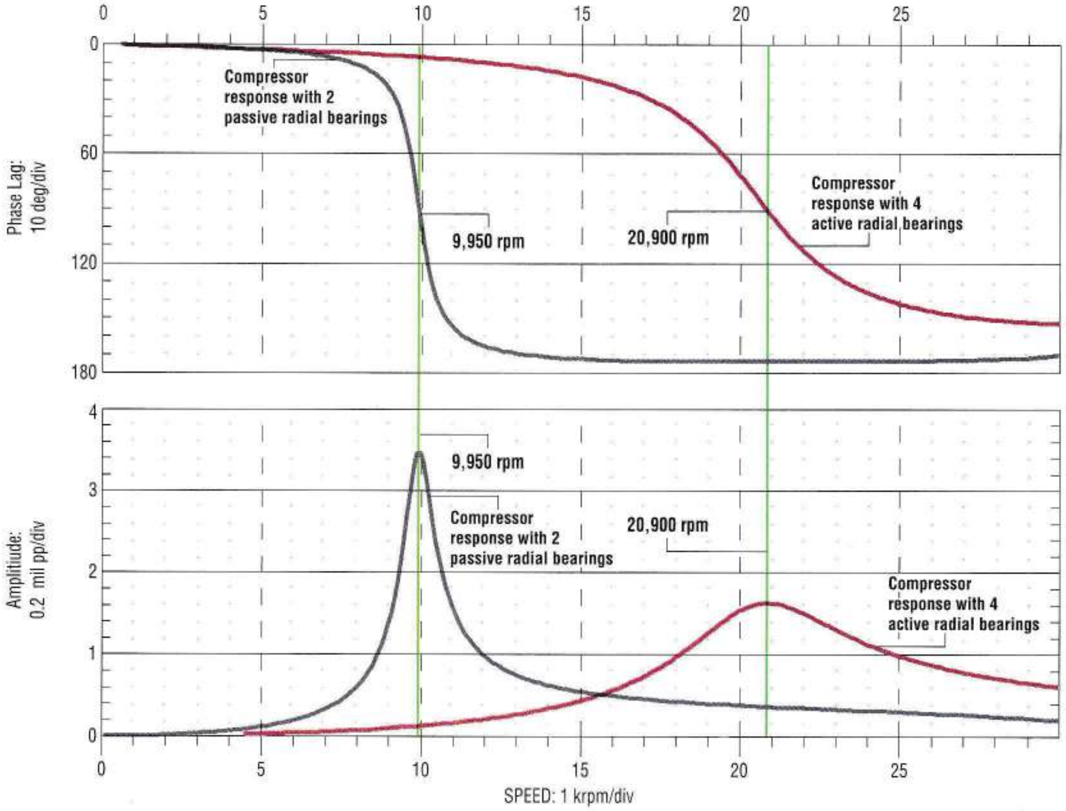

Figure 6. Bode plots showing response of compressor, modeled in Figure 5, with 2 passive or 4 actively controlled radial bearings. (Thrust is passive.)

Conclusions

Phase information is important for the Operators and Machinery Specialists. Trending of startup, shutdown, and steady state data provides critical information for machinery management. The absence of phase information leaves a large gap in the usefulness of this information. Changes in phase can alert the operator before costly machine damage occurs. Bently Nevada's 3500 Machinery Protection System, the Trendmaster® 2000 System, and Data Manager® 2000 System can alert the operator to changes in 1X and 2X amplitude and phase. These Bently Nevada systems were designed to present information in a way that is easy for Operators and Machinery Specialists to retrieve and understand.

Direct amplitude, frequency, and phase information are important in machinery management and diagnostics. Lack of phase information can not only lead to an inability to diagnose a machine problem, but can lead to an incorrect diagnosis. That is why Bently Nevada and the American Petroleum Institute, in its specifications for machinery protection systems, recommend installing a Keyphasor and redundant Keyphasor transducers for phase measurement.

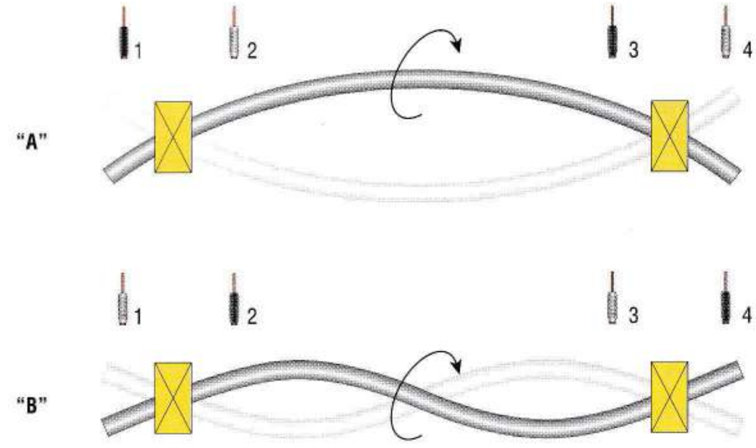

Figure 4. Vibration mode shape of rotor can be determined by comparing phase of vibration at each end of the machine. Poor selection of probe location can lead to ambiguity about operating mode of rotor.

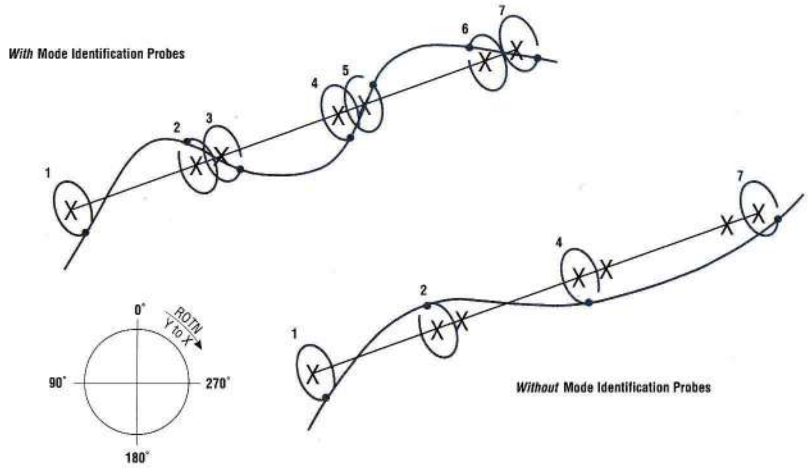
With Mode Identification Probes
1
2
3
4
5
6
7
0°
ROTN
Y to X
90°
270°
180°
1
2
4
7
Without Mode Identification Probes

Figure 5. Too few vibration probes can provide insufficient phase and amplitude data about the true vibration mode shape of the rotor on a complex machine train.

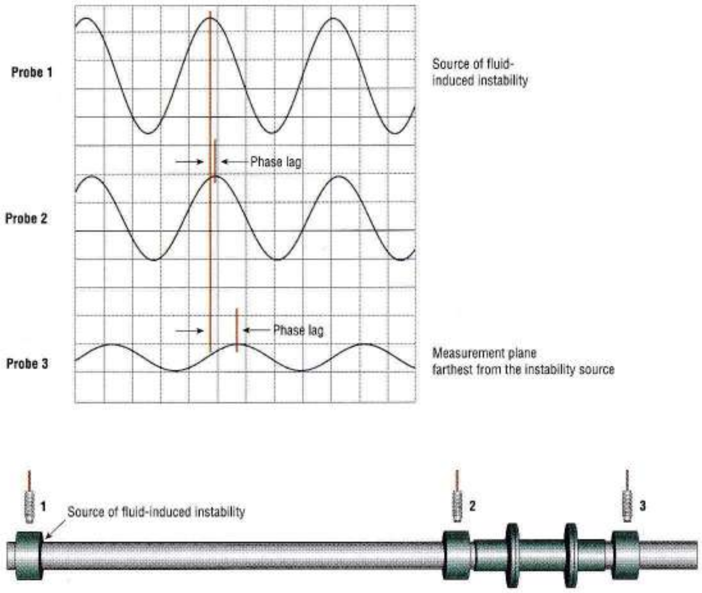
Probe 1
Source of fluid-induced instability
Phase lag
Probe 2
Phase lag
Probe 3
Measurement plane farthest from the instability source
1
Source of fluid-induced instability
2
3

Figure 6. Phase lag of the fluid-induced instability vibration signal increases with distance from the source of the instability.

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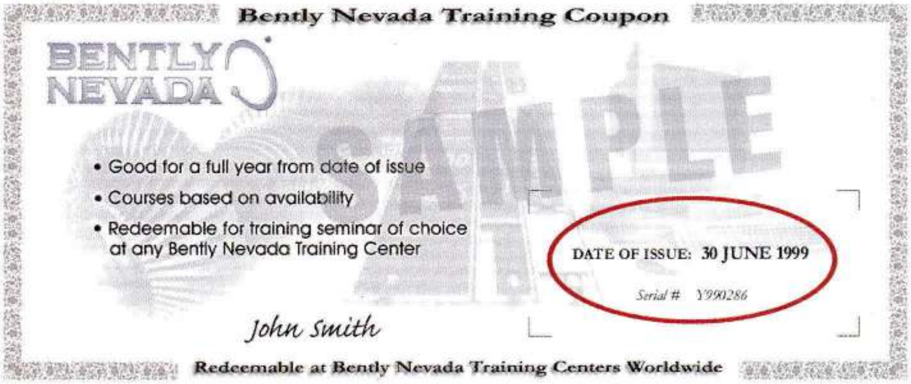

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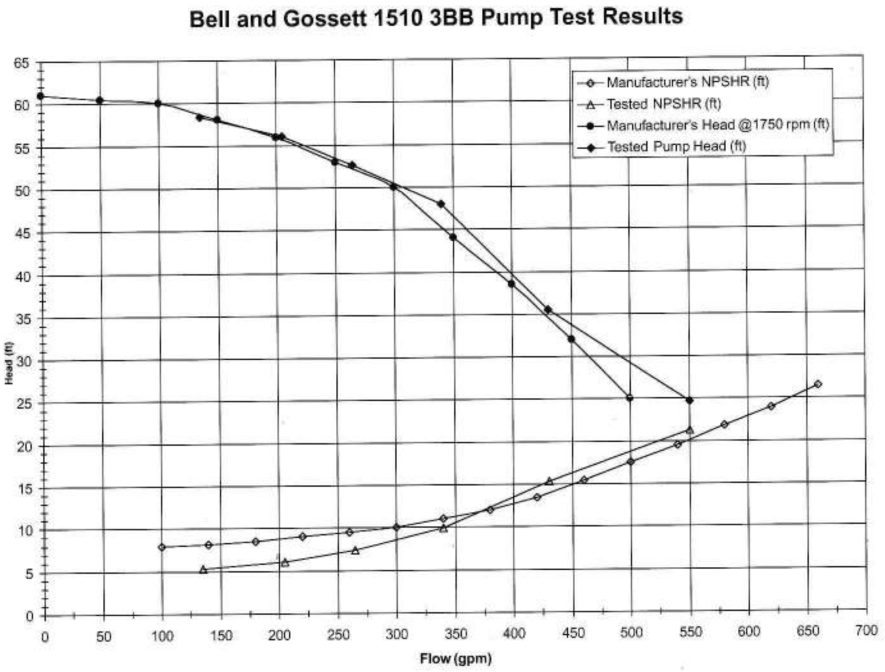

Figure 2. Manufacturer's head curve versus tested head curve.

Handbook also mentions that the noise due to recirculation is louder. This information confirmed our observations.

Our research on centrifugal pump behavior involves taking measurements of vibration, bearing temperature, lubrication condition, and process parameters. These measurements are made at various locations on the motors and pumps to identify and correlate specific operating, vibration, and process conditions. This allows us to assess the effectiveness of different measurements (including dynamic power), transducers, and measurement locations for both machinery protection and machinery diagnostic purposes.

As expected, the most direct measurements provided the strongest signals and clearest picture of the pump's operating condition. Measurements, such as dynamic pressure, direct shaft displacement, and REBAM provide clear and low noise signals, while indirect measurements, such as casing acceleration and acoustic microphone data, are generally more difficult to interpret. In combination, a good picture of the pump's operation is obtained. Our challenge is to determine the best practices for the given machine and operating environment that will provide effective machinery management.

Through our ongoing research in the pump lab and the correlation of this research with our field engineering experience, we expect to pioneer the development of more effective solutions for managing the smaller, often less critical, rolling element bearing machinery. You can follow these developments as we describe our findings in subsequent ORBIT magazines. The topics will include:

- Proper pump selection and installation.
- Cavitation: the silent killer!
- The effects of running off BEP on performance and mechanical integrity.
- Condition monitoring of rolling element bearings and mechanical seals.
- Lubrication systems for rolling element bearings.
- Structural and acoustic resonance.
- Proper alignment and balancing for motor and turbine driven pumps.

References

1. *Pump Handbook*, Second Edition, Karassik, Krutzsch, Fraser, Messina, McGraw Hill, 1986.

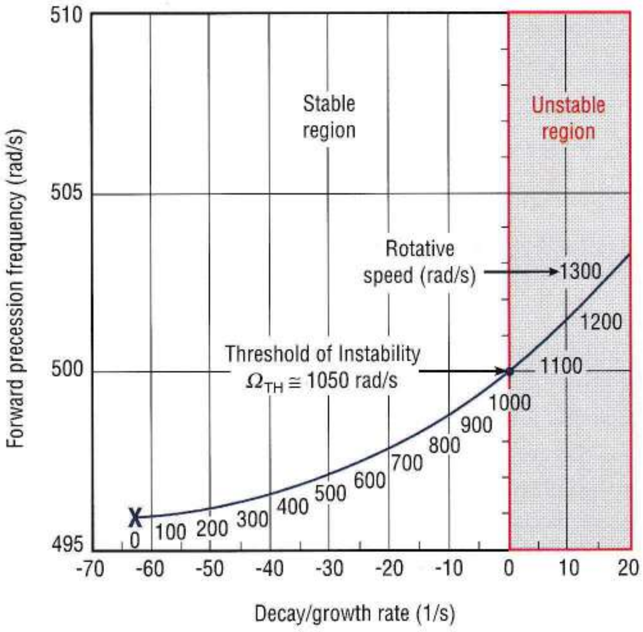

Figure 2. The forward root of a simple rotor system.

further left on the plot that the root exists, the more damping exists to control the decay rate of the rotor motion. When the root encounters the vertical axis (at $\Omega = 1050$ rad/s, Figure 2), the system is marginally stable and the rotor transient motion will neither grow nor decay. This is the Threshold of Instability, and the rotor system will be unstable for rotating speeds above this threshold speed.

The root of interest for absolute stability is the forward precession (above the horizontal axis) root, because the reverse root moves toward greater stability. Figure 2 shows the forward root locus in greater detail. Note that the rotor speed for the Threshold of Instability is 1050 rad/s. However, the precession rate of the motion at that point is 500 rad/s, less than half the rotative speed, which is typical for fluid journal bearings. Therefore, this machine, as described by the model, should not be operated above 1050 rad/s. As the machine stiffness changes, due to changes in operating condition, this stability condition will vary. To study this, families of the locus can be generated for variations in stiffness, damping, and mass to determine the most stable operating regions.

This brief example demonstrates just a few of the features of the root locus technique. Please refer to reference 2 for a more extensive treatment of typical control system design and analysis techniques.

References

1. Evans, W. R., *Control-system Dynamics*, pp.117, McGraw-Hill Book Company, Inc., New York, New York, 1954.
2. Ogata, Katsuhiko, *Modern Control Engineering*, Third Edition, Prentice-Hall, Inc., 1997.